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A Marketing Survey and Assessment of the Potential for Desulfurized Coal

INSTITUTE FOR ENVIRONMENTAL STUDIES

University of Illinois at Urbana-Champaign

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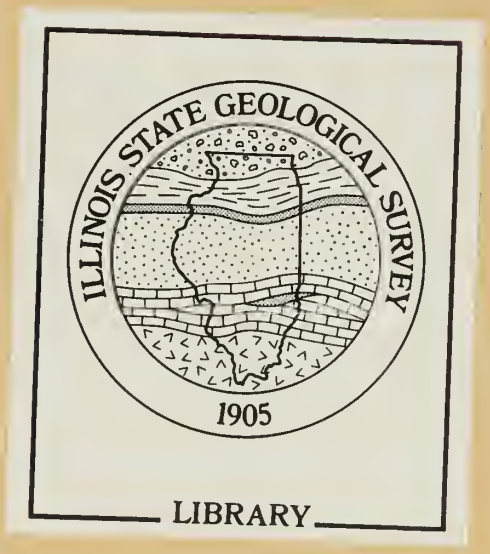

ILLINOIS STATE GEOLOGICAL SURVEY
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A MARKETING SURVEY AND ASSESSMENT OF THE POTENTIAL FOR DESULFURIZED ILLINOIS COAL

by

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August 31, 1987

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ABSTRACT

The overall objective of the reported research has been to measure the market for desulfurized coal. How much of a price premium will consumers pay for reduced-sulfur coal?

Focusing on char and ultrafine products, we have been concerned with preferences regarding sulfur and volatile matter. To address the value of sulfur, we statistically analyzed actual utility coal transactions. Preliminary results indicate a sulfur premium for Illinois consumers in the range $17-24 per ton for a reduction of sulfur of 1 lb./MMBtu.

To measure preferences regarding low volatile product, we conducted a survey of over seventy power plants in the Illinois market area. The results of this analysis suggest that the penalty for low volatility is on the order of $3-4/ton for each 5 percentage point reduction in volatile matter.

All results are preliminary and await further analysis. However, some R & D conclusions are forthcoming. Volatile matter is very important to existing consumers. Furthermore, a significant premium will be paid for lower sulfur coal.

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CHAPTER I. INTRODUCTION

A. PROBLEM STATEMENT

Air pollution regulations of the past two decades have had a big impact on coal markets. Most coal is used for industrial and electric utility combustion, and coal combustion accounts for major shares of the particulates, sulfur and nitrogen oxides, and certain other pollutants released into the atmosphere. Pollution regulations have induced many industries and utilities to use cleaner coals or shift to other fuels.

Illinois contains more coal reserves than any other state. Illinois coal can be shipped cheaply to midwestern industries and utilities and its combustion qualities generally are good. But, most of the coal in Illinois contains too much sulfur to be burned alone under federal air pollution standards. Utilities and industries have turned increasingly to lower sulfur alternatives, from the East or West, to fuel their furnaces. The market for coal from Illinois has stagnated while the overall market for coal has grown. Renewal of Illinois' coal industry depends on overcoming the sulfur problem.

Many scientists are studying and testing methods for removing sulfur from coal. Generally, these go beyond conventional physical "cleaning" processes, which are already used at many mines. More sophisticated methods are likely to be more costly, and it is not clear that the resulting products will fetch prices sufficient to cover the additional processing costs as well as the regular mining and transportation costs. To guide research in this area, fundamental information is needed about the market value of reducing the sulfur content of Illinois coal. That is the focus of the research reported here.

B. BACKGROUND

The issues involved in the acceptability of reduced-sulfur coal are similar to those that have arisen in switching boilers designed for relatively high sulfur bituminous coal to subbituminous low-sulfur coal or deep-cleaned coal. A number of coal (and boiler) characteristics bear on the ease with which one coal can replace another in existing boilers; e.g., grindability, particle size, ash fusion temperature, content and composition, volatility, and sulfur content. The ease and expense of adapting to coals of different composition, as well as the prices of fuels currently in use, govern the price which a coal consumer would be willing to pay for different fuels.

There has been a fairly large literature on this subject. For instance, Higazy and Kenning (1983) discuss their experience at Detroit Edison in modifying plants designed for eastern bituminous coal so that they can burn western subbituminous coal. Curlett et al. (1983) consider a variety of coal characteristics important in designing new power plants, but focus in particular on ash fusion temperature and grindability as the two characteristics which have the most influence on plant performance and thus cost. In a related vein, Buden et al. (1979) examine the changes which take place when particular coals are deep-cleaned and the effect of this on generator performance and cost.

Several authors have examined the effect of ash content, and to a certain extent moisture, on plant performance. Barrett et al. (1981), Phillips and Cole (1980) and Honea et al. (1981) examine actual performance histories of plants as a function of ash and moisture levels. The Honea et al. study concerned lignite and San Juan coals, both very high

in ash and thus not particularly germane to this study. However the Barrett et al. study concerned a number of TVA power plants so is of potential importance to this project. Both the Phillips and Cole and Barrett et al. studies generate a statistical relationship between heat rate, outage rate and ash content.

There has not been a great deal of work on trying to quantify the cost-quality tradeoff in coal, particularly as it pertains to desulfurized coal. Both the Department of Energy and the Electric Power Research Institute have been concerned with this question, although largely indirectly. The DOE is interested in fuel switching but primarily from oil to coal.[1] EPRI is more directly interested in this issue and has sponsored a great deal of work on the problems of switching from one coal to another.[2]

In examining the potential market for desulfurized Illinois coal, one must consider not only current markets for Illinois coal but probably more important, coal users in Illinois or nearby states which are currently using low-sulfur coal. Currently (1986), Illinois sells roughly a third of its utility coal within Illinois.[3] Slightly less is sold to Missouri and about a sixth is sold to Indiana. Remaining customers are as far away as Georgia and Florida, making up total 1986 utility sales of Illinois coal of nearly 56 million tons (total coal sales were just over 61 million tons). Most current utility customers use Illinois coal in

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[1]See for example the discussion in Energy Information Administration (August 1985).

[2]See for example, EPRI (July 1984).

[3]Energy Information Administration (March 1987).

older plants subject to relatively weak State Implementation Plan (SIP) regulations. Until these facilities are retired, these markets should not be in jeopardy unless environmental regulations change. However, if an acid rain bill becomes law, as an example, these customers could disappear overnight.

A better long-run market is for users currently buying high-cost low-sulfur fuel. For instance, nearly a third of the roughly 31 million tons of coal burned by utilities in Illinois in 1985 was low sulfur coal, and it fetched a $15-30 per ton premium over local high-sulfur coal. Neighboring states of Minnesota, Wisconsin, Iowa and Missouri consumed roughly 33 million tons of low-sulfur coal in 1984. If Illinois successfully took over this market, state production would rise on the order of 70%. The question is, can Illinois coals be desulfurized for $10-20 per ton. Further, would utilities be able to live with the physical characteristics of these desulfurized coals or would they need more of a price break to make them attractive?

C. OVERVIEW OF RESEARCH

The research reported herein attempts to estimate the market value of treatments that can reduce the sulfur content of coal. The research begins with an examination of the forces shaping the market for Illinois coal and technologies for reducing sulfur levels. It is clear, from this review, that there are definite bounds on the value of reducing sulfur levels; bounds resulting from the availability of naturally low sulfur coals, the capacity to mix coals, and from the regulatory environment. Moreover, sulfur contributes in positive ways to some aspects of boiler

operation, so many users do not want sulfur to be far below permissable levels. These considerations, as well as experience with the operating characteristics of particular boilers, are the basis of fuel purchasing decisions made by electric utilities.

A variety of technologies for reducing sulfur levels are being studied, including augmented physical cleaning, chemical processes, and hydropyrolysis. Generally, physical methods remove only inorganic sulfur fractions, up to about 30% of total sulfur. For many Illinois coals, this is not sufficient for compliance with pollution standards. Chemical processes can remove some of the organic fractions as well. Combinations of physical and chemical processes may be needed, and these are being explored in some laboratories. An alternative is hydropyrolysis, which decomposes coals into char, oil, gas, and water. Each fraction has some economic value. The solid product, char, can exhibit acceptable heat content and low sulfur levels, but ignition can be difficult and combustion can be unstable. In general, all of these processes alter coal in several fundamental ways, not only in terms of its sulfur content.

Two issues are confronted in attempting to measure the potential value of desulfurized coal. One concerns abstracting from the myriad of different characteristics of desulfurized coal, the few key characteristics which are most important to potential consumers. The other issue concerns valuing those key characteristics.

From the technology review and discussions with knowledgeable scientists, it was clear that desulfurization would change many attributes of coal: its size distribution, moisture, ash content, volatility, heat content, and others. It was impossible to focus on all of these. After

extensive discussion with the CRSC, it was decided to focus on sulfur content and volatility. These were determined to be particularly critical parameters and were selected for investigation. Because electric utilities consume most coal, and constitute the largest potential market for Illinois coal, we concentrate on the demand of the utility industry.

Having identified sulfur and volatility as the two characteristics of desulfurized coal on which to focus, the next issue is how utilities view and value these characteristics. Measuring the value of reduced sulfur is facilitated by observing actual coal transaction and measuring the actual premia utilities attach to low sulfur.

The U.S. Department of Energy (DOE) collects data on all coal purchases by domestic electric utilities, including prices paid and the heat, sulfur, and ash content of the coal. These data were used in this study to estimate the worth of changes in sulfur levels using a technique known as hedonic analysis. Our preliminary results are that this worth varies with the original sulfur level of the coal which is desulfurized; a 1 pound sulfur per million Btu (lb./MMBtu) reduction is worth more for 2 lb./MMBtu parent coal than for 3 lb./MMBtu parent coal. We have found the marginal value of sulfur reduction ranges from about $0.70/MMBtu/lb./MMBtu to slightly more than $1.00/MMBtu/lb./MMBtu. This is the unit "discount" or penalty applied to coal containing sulfur. The total discount per ton of coal is the product of the unit penalty and the sulfur content. Thus the total penalty would be reduced by reducing the level of sulfur.

Notably absent from the DOE data is information on volatility, nor is transaction information with respect to this parameter available

elsewhere. In order to investigate the value of volatility, we had to generate new data. This was done through a sample of all electric utilities that purchased Illinois coal in 1985. A thorough investigation of survey methodology provided background for our construction of an instrument which we then mailed to over seventy power plants in the Illinois market area (a response rate of about 80% was achieved). Reduced-sulfur coals were specified in the survey as containing from 15.1% to 35.3% volatile matter. This range extends well below levels to which most utilities are accustomed. Preliminary results indicate that volatility is highly valued; an increase from 25.0% volatile matter (by weight) to 27.5% volatile matter was valued by the respondents at about 8¢/MMBtu.

The survey was also designed to permit analysis of the value of sulfur content, for comparison with results of the hedonic analysis. The sulfur specifications ranged from 0.45 lb./MMBtu to 1.78 lb./MMBtu, all near or below allowable standards. Preliminary analysis of the results failed to reveal a significant value for changes in sulfur in this range. Further interpretation of this result, in light of the hedonic analysis, is needed.

D. ORGANIZATION OF REPORT

An overview of the coal market, and the position of Illinois coal in the market, is provided in Chapter II of this report. Chapter III contains a brief review of leading technologies for reducing the sulfur content of coal. In Chapter IV, coal purchasing practices are described.

These practices capture the fundamental trade-offs that are reflected in market prices.

Chapters V and VI describe the two different efforts to estimate the market value of attributes of reduced-sulfur coal. The former chapter contains the hedonic analysis of Department of Energy data on actual coal purchases by electric utilities in 1985. The second empirical analysis, reported in Chapter VI, focuses mainly on volatility and utilizes primary data gathered in the survey of electric utilities in Illinois' market area. Conclusions from this study and implications for research and development are drawn in Chapter VII. Several appendices containing data and the survey instrument accompany the body of the report.

E. ACKNOWLEDGEMENTS

This research has been made possible by Illinois' Center for Research on Sulfur in Coal (CRSC), a division of the Illinois Department of Energy and Natural Resources. We appreciate the Center's sponsorship, and the counsel of our project manager, Dan Banerjee, as well as of Bill Wells and John Lytle, also of the CRSC.

Our understanding of sulfur reducing technologies has been greatly enhanced by discussions with staff members of the Illinois State Geological Survey, including: Larry Camp, Carl Cruse, Hank Ehrlinger, Richard Reed, Massoud Rostam-Abadi, Gus Ruch, Richard Shiley, and Mike Stevenson. Extremely valuable insight into fuel purchasing practices of electric utilities was gained from John Planck, Ron Rainson, and Don Sylvester of Central Illinois Light Company and Phil Rogers of Illinois Power Company.

Mr. Scott Kunkel of Commercial Testing and Engineering, Inc. provided expeditious testing of some reduced-sulfur coal samples.

Karol Lister of the University of Illinois Survey Research Laboratory, V. Kerry Smith of Vanderbilt University, Alan Randall of Ohio State University, and Rich Bishop of the University of Wisconsin gave us valuable comments during the design of our survey.

The fuel purchasing officials who responded to our survey provided essential information. They were assured that their answers would be held in confidence, and we have made every effort to do so.

Finally, Eileen McCulley deserves our thanks for very efficient and cheerful typing and preparation of numerous materials for this project, including this final report.

While we are grateful for the contributions of these individuals, the authors alone are fully responsible for the contents of this report.

CHAPTER II. TRENDS AND MARKET FORCES IN THE US COAL INDUSTRY

The public perception of the coal industry, prior to the sharp increase in oil prices, was that the industry was in decline. That perception changed dramatically following the 1973 oil price increase. A close examination of the industry over the past few decades paints a different picture. Coal production has grown steadily since about 1960 despite oil being at its all-time cheapest in the 60's. And is true that after the OPEC oil price action of 1973, coal production boomed, although output growth has slowed in the 1980's. However, hidden beneath the overall growth is a major shift in the regional structure of coal markets, a shift due large to the Clean Air Act of 1970 and its 1977 amendments. High-sulfur coal markets have stagnated or declined as a result of tightened environmental regulations. Low-sulfur markets have grown rapidly, as a result of increased overall demand for coal and particularly as a result of demand shifting away from high-sulfur producers.

In this chapter we take a closer look at the US coal market in order to better understand the forces that have shaped the demand for Illinois coal and which will shape that market in years ahead.

A. HISTORIC REGIONAL COAL PRODUCTION AND CONSUMPTION

The only thing that has been constant in the coal industry is change, fluctuation and periods of boom and bust. Coal output began to grow rapidly in the US in the late 19th century. Production reached 579 million tons in 1918, up from 212 million tons in 1900. During the 1920's and 1930's production leveled off and then declined, falling to

310 million tons in the depression year of 1932. World War II of course spurred production up to a high of 620 million tons in 1944. After the war, coal gradually declined in importance, with output falling to 402 million tons in 1961. From 1961 coal output began to grow again. Since 1961, the coal industry in the US has steadily expanded, increasing output in nearly every year. Furthermore, this expansion preceded the oil price rise of 1973. Figure 2-1 shows historic production figures for the US and its main production regions. Coal production more than doubled in the 1960-85 period, a growth rate in excess of 3% per year.

A striking characteristic of the post-1960 expansion in the US coal market is its non-uniform incidence on various regions of the country. Throughout the 1960's, expansion was relatively uniform. But since 1970, the West, largely the Powder River basin of Montana and Wyoming, has been responsible for nearly all of the growth in the coal market. Some growth has also occurred in the low-sulfur basins of the East (e.g., East Kentucky) but at the expense of high sulfur producers, largely in the Midwest, particularly Illinois. Illinois production peaked in the early 1970's, and has declined slightly since then. Production now is about the same as it was in 1965.

Clearly sulfur emission laws were responsible for the decline in high-sulfur coal markets. But why has the overall coal market been booming since the early 1960's, not just since the oil price rises? The answer can be seen by examining the patterns of consumption. In fact, the coal industry has undergone a dramatic change in the last thirty to forty years. Figure 2-2 shows sectoral consumption of coal in the U.S. from 1949 to the present. As can be seen, Residential, Commercial and

Transportation use dropped dramatically in the post-war era. Industrial and coke use remained relatively stable throughout the 1950's and 1960's, but has declined significantly in the 1970's and 1980's. In contrast, use of coal for electricity generation has grown steadily at a rate of nearly 6% per year in the 1949-85 period. Non-electric power uses have essentially vanished while electric power use has grown dramatically from 17% of the coal market in 1949 to 85% in 1985. Thus the downturn in the 1950's followed by an upturn in the 1960's and 1970's was the result of a rapid decline in other uses, eventually overcome by steady growth in electric power.

B. THE ROLE OF AIR QUALITY LEGISLATION

While overall growth in the coal market has been due to a steady rise in utility demand for coal, the overall shift away from high sulfur coal to lower sulfur coal has been due to environmental regulations. The Clean Air Act of 1970 set up the Environmental Protection Agency with authority to reduce air emissions, including sulfur oxides. Control of sulfur oxides was to be two tiered. Emitters existing at the time of the legislation would only be controlled to the extent necessary to reduce ambient concentrations of sulfur dioxide (concentrations in the surrounding air) to levels below nationally specified standards to protect human health and welfare. The Clean Air Act left it up to states to decide which emitters would be controlled to what extent in order to meet the National Ambient Air Quality Standards.

A major target of state regulations to meet the Clean Air Act goals was power plants using very high sulfur coals. Generally speaking,

states required these plants to switch to lower sulfur coals, though stopping short of changes that would greatly increase generating costs or disrupt local high-sulfur coal markets.

A second component of the 1970 Clean Air Act was to have a more devastating effect on high-sulfur coal interests--the New Source Performance Standards. The Clean Air Act stipulated that all emission sources constructed after the Act went into effect would have to emit as little as technologically feasible, with technological feasibility defined by the EPA through New Source Performance Standards. In the case of electric power generation from coal, the EPA stipulated that emissions could not exceed 1.2 pounds of SO_2 per million Btu of fuel input, leaving it up to the emitter how to achieve this limit. Virtually without exception, the cheapest way for new power plants to meet this standard was to use low-sulfur coal. In the Midwest, this meant using low-sulfur coal from the western Great Plains. For the East, this meant using low-sulfur coal from West Virginia and Eastern Kentucky. Illinois, and the Midwest in general, suffered relative stagnation if not decline during the 1970's and 1980's while the West and Eastern Kentucky enjoyed a tremendous boom.

Recognizing the implications of the New Source Performance Standards on utility boilers for the future of the midwestern coal industry, legislators and coal interests in the Midwest (in conjunction with environmentalists) were successful in having the New Source Performance Standards changed to require the removal of 70-90% of the original sulfur in the coal either before it could be burned or after burning in a new utility boiler. These revised standards were incorporated into the 1977 amendments to the Clean Air Act. These revisions removed much of the ad-

vantage of low-sulfur coal, because it too was subject to control. It is too early to see the extent to which these revised New Source Performance Standards have helped the market for Illinois basin coal.

Clouding the future of coal markets is the possibility of Federal legislation to control "acid rain." Two types of proposals have been introduced in Congress. One calls for a roll-back of sulfur and nitrogen emissions from existing plants by whatever means states deem appropriate. To a large extent this would occur through switching to low-sulfur coal. The other type of bill requires the use of technological controls to achieve the emissions reduction, effectively precluding fuel-switching as a means for emissions reduction. Clearly the high-sulfur coal market could be very significantly impacted by acid deposition legislation, especially if fuel switching is allowed.

C. SIGNIFICANCE OF THE UTILITY MARKET TO ILLINOIS

Electric utilities consumed 90% of Illinois coal production in 1985 (Figure 2-3).[4] Table 2-I indicates where Illinois coal is consumed by electric utilities. While the Illinois market extends well into the South, all the way to Florida, the bulk of the market is nearby. Missouri and Illinois utilities are responsible for 57% of Illinois coal consumption by utilities. In those two states, well over half of utility coal consumption comes from Illinois. While a variety of other states buy an appreciable amount of coal from Illinois, no states are more reliant on Illinois coal than Missouri and Illinois. Several states, particularly Florida, rely on Illinois coal for around a fifth of their

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[4]USDOE (1986).

coal requirements. A number of other states use a nominal amount of Illinois coal.

Illinois' coal market extends to the South for two very good reasons. First, relatively cheap barge and rail transit routes exist to the South. Second, competing coals with the same or lower sulfur content lie to the east and west. To the east of Illinois are high-sulfur coal deposits in Indiana and Ohio. It would be difficult for Illinois coal to compete with these local coals considering transportation costs. To the west, Powder River coals are even more attractive because of the smaller transportation costs. This fact, coupled with increased transport costs associated with moving Illinois coals to points west, makes Illinois coal unattractive in western markets. Thus the Illinois market extends south, through relatively cheap transportation corridors.

Table 2-II lists all power plants using Illinois coal in 1985. There are two things to notice from the Table. One is that while there are many plants using Illinois coal, a small number of plants are very heavy users. For instance, the Baldwin, Gibson and Labadie plants together consume a quarter of all Illinois coal production. Another interesting feature is that there is some moderately low sulfur coal coming out of Illinois. Over seven million tons, or an eighth of Illinois production, had delivered sulfur content of less than 2%. Whether this reflects deep cleaning or unusually low native sulfur levels is not known.

D. THE HIGH SULFUR COAL MARKET

Where is Illinois positioned in the high sulfur coal market? There are really five states that constitute the major high-sulfur coal producers: Ohio, Illinois, Indiana, Western Kentucky and Northern West Virginia. Together, these states produced roughly 180 million tons of coal in 1985, of which Illinois' 30% share was larger than any other state. West Virginia, Ohio and Kentucky each have about 18% of the market. Ohio and Indiana largely serve own-state markets (although not exclusively). West Virginia serves mainly the mid-Atlantic and New England states. Illinois and Kentucky compete head-to-head in Southern markets. Because of Kentucky's location, one would expect that state to be slightly better poised in the deep south. Interestingly, Illinois has captured the entire Missouri market. Despite the proximity to Kentucky, no high-sulfur coal moved to Missouri from Kentucky in 1985 for electric power generation.

Thus Illinois has managed to capture the bulk of the high-sulfur coal market, at least in states which are not high-sulfur coal producers themselves. This is good for Illinois but suggests the vulnerability of Illinois coal in a shrinking market. In the event of nationwide reductions in consumption of high-sulfur coal, Illinois output is likely to decline significantly.

E. CURRENT PATTERNS OF COAL QUALITY

Table 2-III shows the average sulfur content of coals burned by electric utilities in 1985. Note that over half the states represented consume coal averaging less that 1% sulfur. Furthermore, the state

consuming coals with the most sulfur on average is Kentucky, but even Kentucky's consumption averages well under 3% sulfur. Clearly lower sulfur coal dominates consumption patterns.

F. PRODUCTIVITY AND PRICES

In addition to the regional shifts in demand and production that have occurred over the past few decades, there has been a dramatic shift in the cost of providing coal. Figure 2-4 shows the average price of coal over the last twenty-five years as well as productivity levels. As can be seen, productivity declined dramatically in the early 1970's and was accompanied by a significant price rise. Conversely, the 1980's have seen increases in productivity. This increased productivity, coupled with excess capacity in the coal industry has lowered prices markedly. The implications for this study are that because the coal market is so volatile, any measured sulfur or volatility penalty will apply to the measurement period only and may not apply for other time periods, either in the past or in the future.

G. CONCLUSIONS

In this chapter we have seen the fragile state of high-sulfur coal markets. Although the coal market in general has been expanding over the last three decades, markets for high-sulfur coals have stagnated or declined. Illinois has done remarkably well in positioning itself in the high-sulfur coal market. However, the future of Illinois coal is probably not bright unless cost-effective ways are found to eliminate sulfur.

Figure 2-1: Historic Coal Production

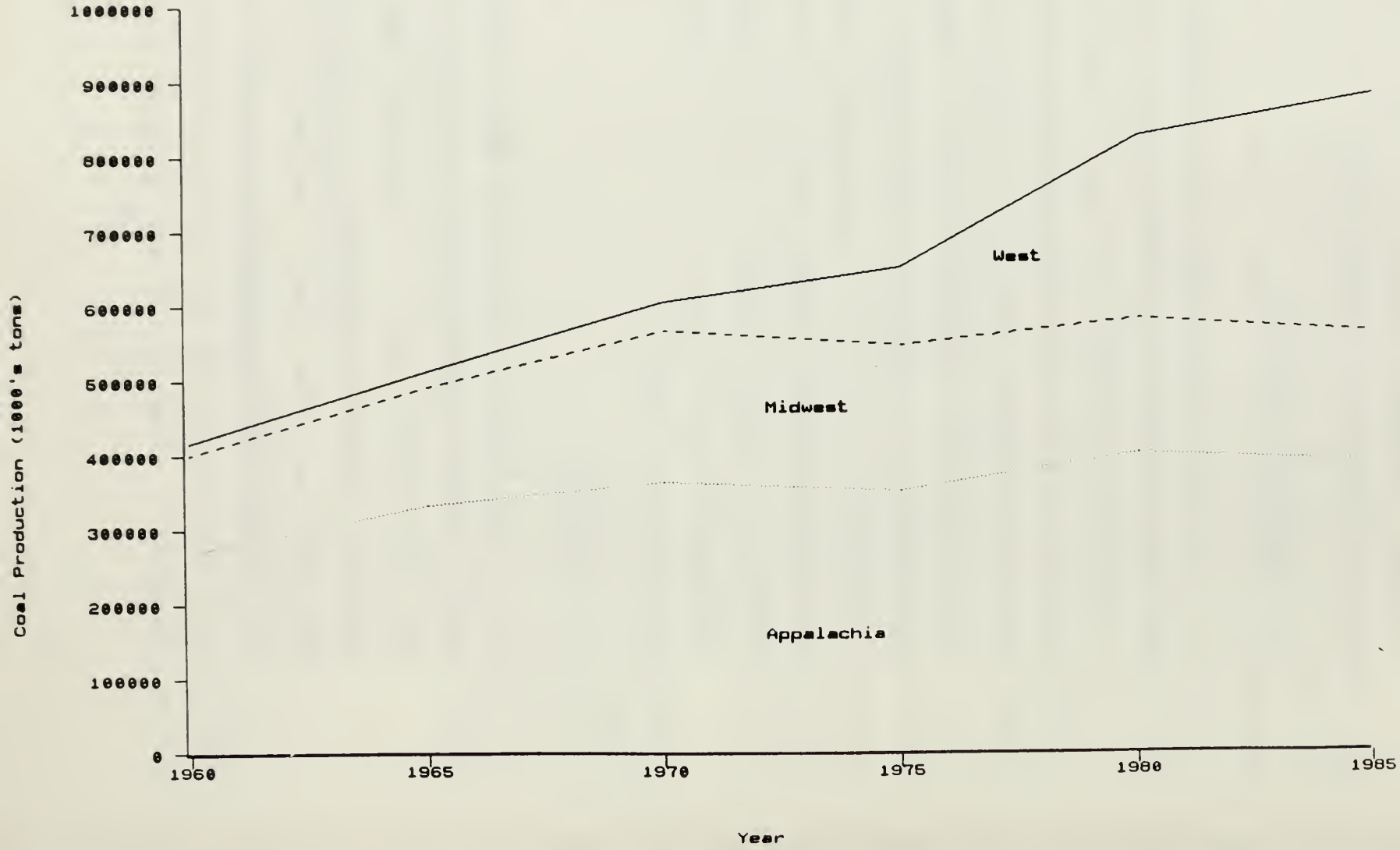

Figure 2-2: Historic US Consumption of Coal by Sector

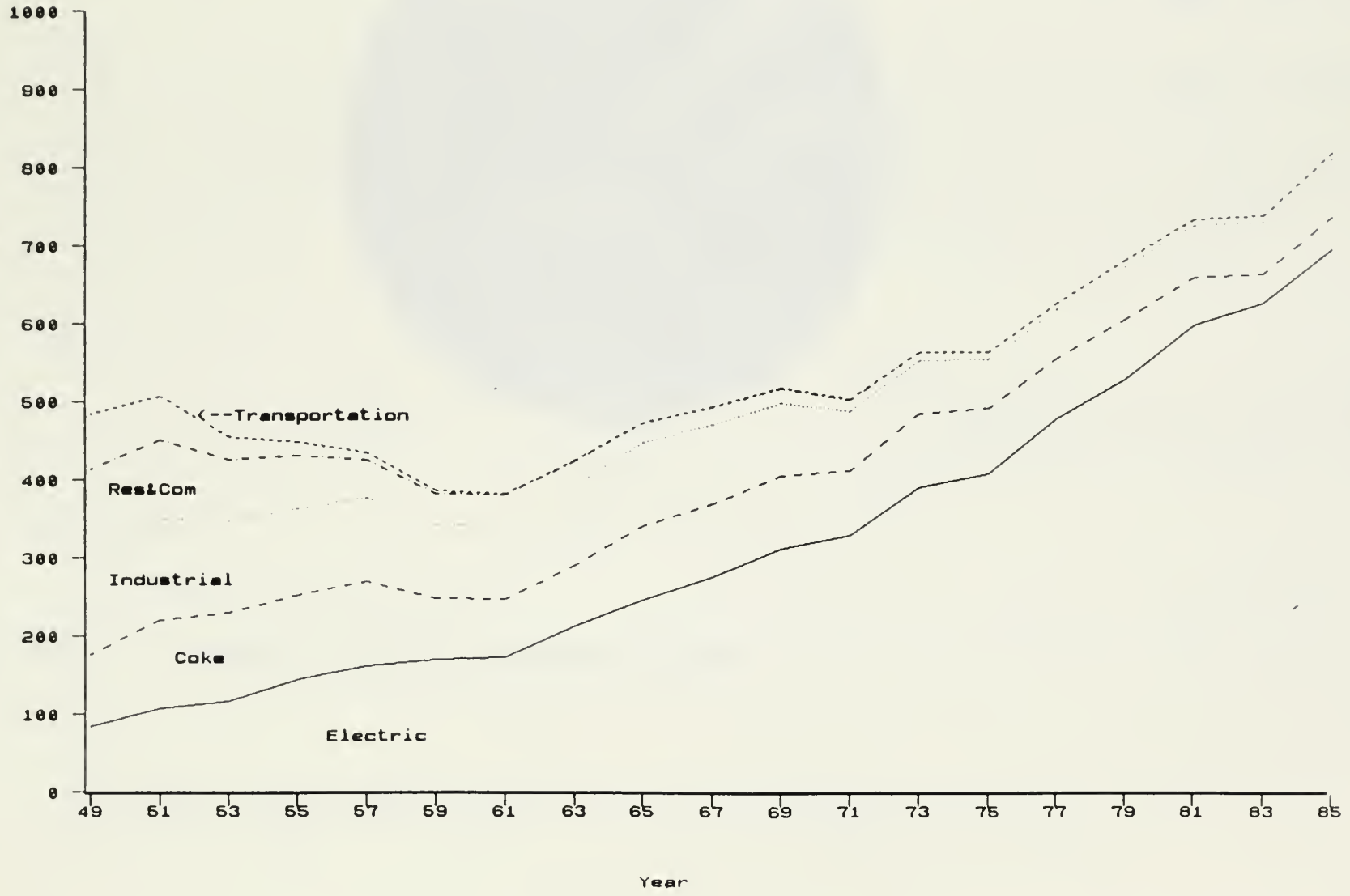

Figure 2-3: 1986 Coal Consumption, Illinois

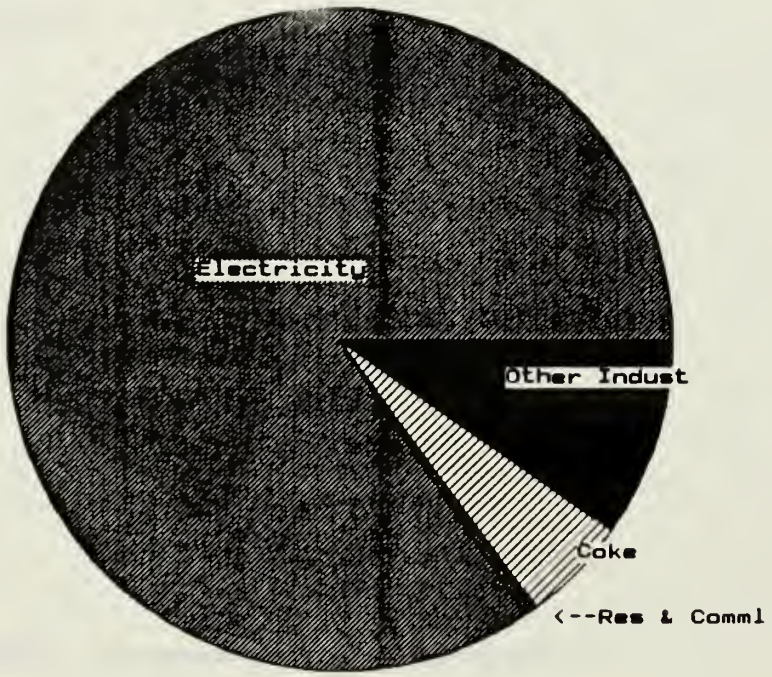

Figure 2-4: U.S. Coal Prices and Productivity

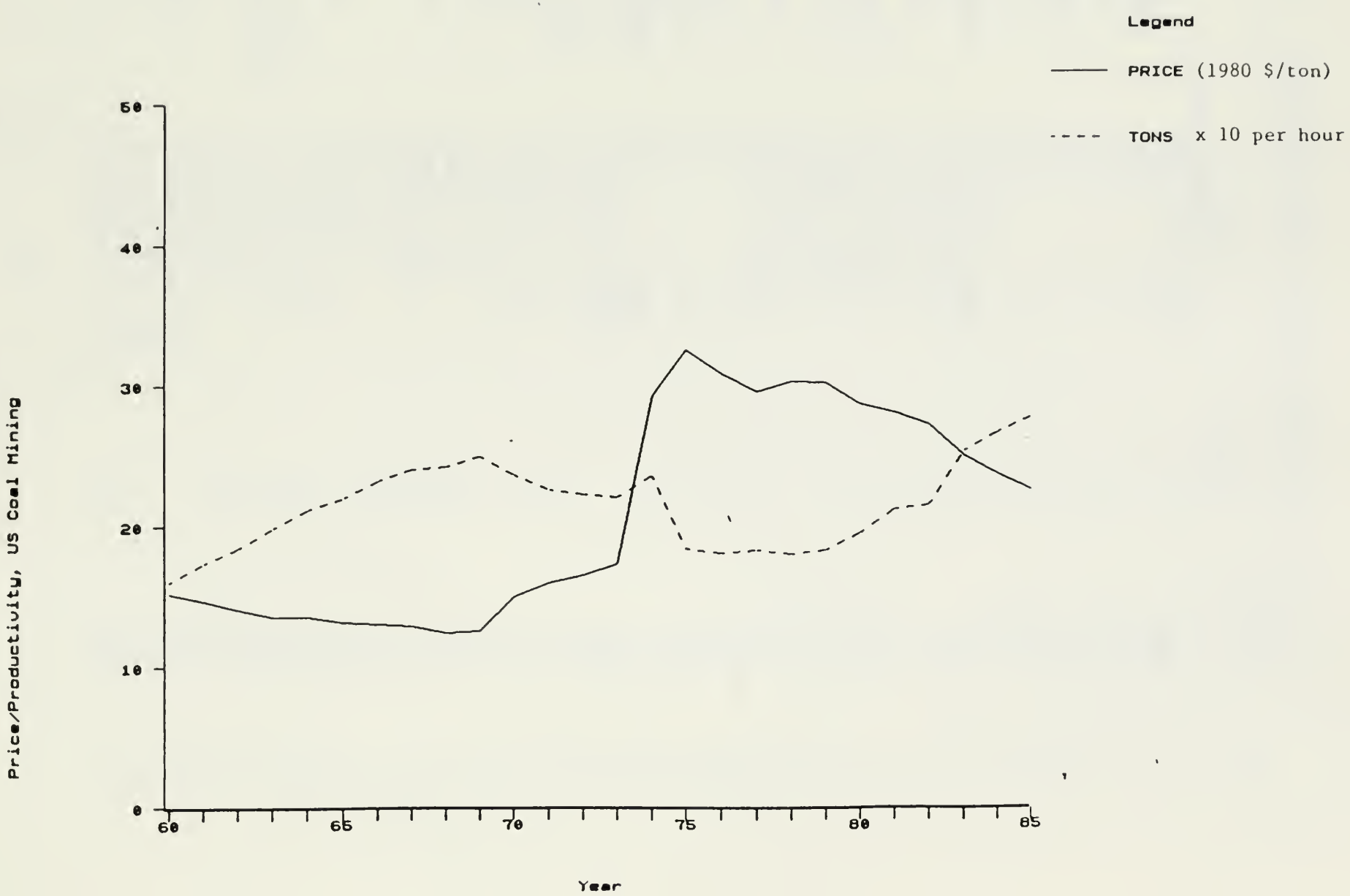

Table 2-I: 1985 Coal Consumption by Electric Utilities (1000's tons)

	SOURCE OF COAL	
STATE	IL	TOTAL
AL	2,819	21,525
FL	3,723	16,640
GA	3,131	24,201
IL	16,541	31,682
IN	7,653	36,224
IA	1,959	12,345
KA	481	14,088
KT	117	23,405
MO	13,419	22,065
TN	1,389	18,178
WI	1,248	15,357
TOTAL	52,480	235,710

Table 2-II: Electricity Plants Burning Illinois Coal in 1985

Plant	Utility	State	1985 IL Coal Use	Avg %
Madrid	Assoc. Elec. Coop	MO	2,492	3.2
Chamois	Central Elec Coop	MO	71	2.3
Duck Creek	CILCO	IL	928	3.4
Edwards	CILCO	IL	66	3.4
Coffeen	CIPS	IL	1,970	3.7
Grand Tower	CIPS	IL	150	2.8
Meredosia	CIPS	IL	552	2.6
Newton	CIPS	IL	1,060	2.6
Kincaid	Comm. Ed.	IL	2,516	3.3
Alma-Madgett	Dairyland Power		103	3.1
Genoa #3	Dairyland Power	IL	222	3.0
Stoneman	Dairyland Power	IL	34	3.2
Fair	E. Iowa L+P	IA	75	2.7
Joppa	Elec. Energy	MO	1,580	1.9
Atkinson-McDon.	Georgia Power	GA	697	2.5
Wansley	Georgia Power	GA	2,991	2.5
Yates	Georgia Power	GA	1,558	2.6
Crist	Gulf Power		1,355	2.8
Morom	Hoosier Energy	IN	967	3.0
Baldwin	IP	IL	4,669	2.8
Hennepin	IP	IL	745	2.8
Vermillion	IP	IL	311	2.4
Wood River	IP	IL	418	0.9
Tanners Creek	AEP	IN	96	2.8
Dubuque	Interstate Power		179	2.9
Kapp	Interstate Power		547	3.0
Prairie Creek	IA Elect L + P	IA	336	2.4
Sutherland	IA Elect L + P	IA	75	2.4
6th Street	IA Elect L + P	IA	49	2.3
Burlington	IA Southern Util	IA	144	3.0
Riverside	IA-IL G + E		132	2.4
Kaw	Kansas City	MO	201	2.6
Quindaro	Kansas City	MO	292	2.6
Ghent	Kentucky Util	KY	76	2.8
Watson	Miss. Power	MS	172	2.5
Sibley	MO. Power	MO	538	3.2
Muscatine	Muscatino P + W		488	2.9
Bailly	N. In Pub Serv	IN	481	3.1
Michigan City	N. In Pub Serv	IN	936	2.8
Rollin Schahfer	N. In Pub Serv	IN	724	3.2
Gallagher	Pub Serv Ind	IN	156	2.9
Gibson	Pub Serv Ind	IN	5,592	2.3
Silver Lake	Rochester DPU		175	1.5
Seminole	Seminole Elec Coop		692	2.6
Sikeston	Sikeston Mun. Util		277	2.5
Marion	So. IL Power Coop	IL	657	2.9
Dallman	Springfield W, L + P	IL	680	2.9

Table 2-II (con't):

Lakeside	Springfield W, L + P	IL	22	2.9
Big Bend	Tampa Elec.	FL	1,694	3.0
Allen	TVA	TN	51	2.7
Cumberland	TVA	TN	133	2.4
Johnsonville	TVA	TN	1,241	1.8
Shawnee	TVA	TN	107	.63
Widows Creek	TVA	TN	400	.93
Labadie	Union Ele	MO	5,760	2.4
Meramec	Union Ele	MO	519	1.3
Rush Island	Union Ele	MO	2,781	1.0
Sioux	Union Ele	MO	1,133	3.0
Oak Creek	Wisc Elec Power	WI	1,057	2.2
Edgewater	Wisc Elec Power	WI	49	3.7

Table 2-III: Average Sulfur Level of Coal Burned by Electric Utilities in 1985 by State

State	Average Sulfur (%)
KY	2.7
OH	2.5
MO	2.4
IN	2.3
PA	2.1
NH	2.1
NY	1.9
IL	1.9
TN	1.9
WV	1.8
GA	1.8
FL	1.8
DE	1.8
AL	1.5
MD	1.4
NJ	1.4
MS	1.3
SC	1.3
MA	1.2
WI	1.1
SD	1
MN	0.9
KA	0.9
VA	0.9
IA	0.9
NC	0.9
WA	0.9
ND	0.9
MI	0.8
NM	0.7
MT	0.7
TX	0.6
WY	0.5
UT	0.5
NV	0.5
AZ	0.5
LA	0.5
CT	0.5
CO	0.4
OK	9.4
NE	0.4
AR	0.3
OR	0.3

Source: USDOE (1986)

CHAPTER III. REVIEW OF DESULFURIZATION TECHNIQUES

A. INTRODUCTION

The purpose of this chapter is to present a brief, not excessively technical, overview of the technological alternatives for control of the emissions of sulfur dioxide from coal combustion.

Sulfur emissions from coal combustion may be controlled by one or more of the following broad alternatives:

- Precombustion control technologies
- Sulfur capture during the combustion process
- Flue gas desulfurization

Precombustion technologies are the main concern of this study. So, only a brief reference to the other alternatives is appropriate.

B. COMBUSTION AND FGD CONTROLS

Two leading processes are under development which remove sulfur during combustion: Limestone Injection (LI) and Fluidized Bed Combustion (FBC). Both exploit the sulfur retention properties of limestone. The former injects limestone into the high temperature region of the flame, where calcination occurs. When the calcium oxide moves further downstream of the flame, in the presence of a rich oxygen atmosphere, it captures SO_2. The FBC process combines the above mentioned property of limestone with the fact that the gas temperature in fluidized bed combustors is lower than in conventional boilers. The lower temperature and the favorable pattern of residence times leads to the formation of cal-

cium sulfate (gypsum) from sulfur and limestone. Bullard (1986) mentions that, theoretically, LI and FBC represent the potentially least costly technologies for desulfurization "because short residence times avoid the irreducible volume-related costs of other technologies." There are however some reported drawbacks: the sulfur removal rates under the currently available LI technologies don't comply with NSPS (New Source Performance Standards) for new facilities and some burn tests using FBC have shown serious erosion problems in the combustion bed.

The most widely used approach to the control of SO_2 emissions has been Flue Gas Desulfurization (FGD). The use of flue gas scrubbers seems to present cost problems for small power plants. This is because the cost of FGD equipment represents a significant proportion of the equipment cost of a coal fired station and this proportion increases as the size of plant decreases (Prior, 1977). Furthermore, two or three scrubbers in series often are required to ensure a sufficient control of emissions. Estimates provided by Bullard (1986) indicate that the unit cost of SO_2 reduction using FGD is highest for coals having low sulfur content, and increases at increasing rates as sulfur content declines. This feature stems from the strong dependence of FGD costs on the flue gas volume treated. That makes them most economic when operating at 90% removal rates.

C. PRECOMBUSTION CONTROL

Technologies which remove the sulfur dioxide prior to the combustion process can be grouped into four major categories:

- Coal switching and blending
- Physical coal cleaning
- Chemical coal cleaning
- Hydropyrolysis

1. Coal switching

Coal switching and blending, meaning total or partial substitution of low sulfur for high sulfur coal, may be considered the baseline technological alternative for the control of SO_2 emissions. Since the reserves of coals which contain sufficiently low sulfur to enable standards to be met are restricted to specific geographical locations, usually far from the largest demand centers, this alternative basically involves rail or barge transportation of low sulfur coal. So, one obvious element conditioning the decision to switch coals is the increased delivered cost of coal. Other indirect costs may also have to be taken into account, particularly costs that may be required to modify the plant to use different coals. Widespread and sustained adoption of this alternative appears to be particularly negative for regions producing high sulfur coal such as Illinois and Northern Appalachian basins. Using an engineering cost model and abstracting from the indirect structural costs mentioned above, Bullard (1986) found that significant reductions of sulfur emissions are possible at costs that are not "prohibitive" using transportation of low sulfur coal. He has estimated that reducing total US emissions to 50% of their 1980 levels could be accomplished at roughly \$100/ton SO_2 whereas a 75% reduction would cost approximately \$500/ton SO_2. Further reductions by coal switching are infeasible, given the minimum sulfur content of US coal reserves.

2. Physical Coal Cleaning

Raw coal contains: organic matter (the substantive part of the coal and which releases most of the heat), moisture, pyrites (mineral matter with very distinct physical properties), and other minerals. Sulfur occurs in the organic and pyritic fractions. Organic sulfur is an integral part of the coal matrix and can be removed only by chemical modification of the coal structure. It represents from 30 to 70% of the sulfur content of US coals.

Physical Coal Cleaning (PCC) is widely practiced in the coal industry. It involves separation of raw coal particles with low mineral content from particles with high mineral content. So, PCC is able to remove only inorganic sulfur. Differences in physical and chemical composition of the coal determine enormous variations in the washability of different coals. Coals where the mineral matter is finely disseminated throughout the matrix are more difficult to clean. These differences imply also the nonexistence of a universal approach to PCC plant design. Nevertheless it can be said that there are four main stages in the coal cleaning process -- comminution (size reduction), classifying, separation and dewatering -- and that for the most crucial stage, the separation, most commercial techniques are based on the fact that pyrites have a specific gravity much higher than that of organic matter (5 and 1.15-1.5, respectively). These processes are usually called "Density Separation Techniques."

Almost all raw mined coal undergoes some form of breaking or crushing to reduce large particles to a more manageable size. This also exposes more impurities. Some pyrite liberation can be achieved by

comminution alone, but in a degree that varies from coal to coal. Generally the greater the sulfur content the greater the proportion that can be removed by size reduction. A study by Cavallero et al. (1976) reported in Mellanby-Lee (1986), shows the effect of crushing and density separating on the sulfur content of 455 US coal samples: only 14% of the raw coal samples had a sulfur content lower than EPA standard while 32% of the samples met the standard when crushed to less than 12 mesh and density separated at 50% thermal recovery. In general, the greater the size reduction the greater the liberation of mineral matter, but excessive size reduction is both costly and makes the particle more difficult to clean, dewater and handle.

As mentioned above, most current cleaning technologies separate fraction mainly by differences in density. Wet density separation techniques submerge the coal in a medium (water for the majority of the processes) with an intermediate specific gravity, the raw coal being separated into float ("clean" coal) and sink (mostly mineral matter) fractions. Sometimes these techniques are combined with mechanical separation to enhance the recovery of the clean coal fraction. Several wet density separation technologies are available, namely: jigs, dense medium vessels and cyclones, hydrocyclones, concentrating tables and froth-flotation.

Jigs are the oldest and most common washing device. They use water as the medium and are available in two main types: the Baum jig which is used for coarser coal (150-6 mm) and the Feldspar-bed jig used for fine

coal (13-.6 mm). They are reported to have a good cleaning efficiency[5] at high separating densities (1.5RD or more).

Hydrocyclones also use water as the medium and separate by centrifugal force. (They have the lowest efficiency of all density separation devices but because of low cost they are often used as a preliminary cleaning device.)

Dense medium vessels use as the medium a liquid with higher density than water. The most common liquid is a suspension of finely-ground magnetite (because it has a high relative density and it is relatively easy to recover).

Dense medium cyclones combine the relative density separation with separation by centrifugal force and are used to treat finer particles than the vessels (a size range of 50-.5 mm against 175-12.5 mm). Both have an excellent cleaning efficiency and provide yields near the theoretical.

Concentrating tables combine separation by relative density (water as the medium) with separation by size and shape of the particles. They can effectively remove pyrites finer than 20 μm when the feed is below 0.6 mm, whereas the ash removal rates decrease sharply below 150 μm. Thus, they are best employed as secondary devices to remove pyrites after hydrocyclones or froth flotation.

Froth-Flotation is the most common method of cleaning fine coal (below 0.5 mm). The separation depends mainly on differences in surface properties of the various particles although density also plays a part.

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[5]The concept of efficiency is that in Mellanby-Lee (1986, p. 47): (ash % of raw coal - ash % of clean coal)/(ash % of raw coal - ash % of float coal)

The basic principle underlying the process is the following: "Air bubbles are introduced into a mixture of coal and water; the hydrophobic organic matter surfaces attach to the air bubbles and so the particles with these surfaces are buoyed to the top where they are recovered as a froth, while the hydrophilic mineral matter remains in suspension" (Mellanby-Lee, 1986, p. 35). Many high rank coals can be easily floated with only a froth but the process is not efficient for lower rank or oxidized coals. Studies quoted in Mellanby-Lee (1986) indicate that froth-flotation is effective in removing ash. For instance, in the UK the froth-flotation of a raw coal slurry with an ash content 35% produced a clean coal with 6% ash. Froth-flotation is not however an efficient way for the removal of pyritic sulfur. This is because the contact angle of pyrites is very similar to that of organic matter and thus they tend to float with the coal. Various ways of overcoming this problem are being developed. Some exploit the fact that, due to a much higher density, the organic fraction appears in the froth much faster than pyrites do. So most of the coal can be recovered before pyrites appear in the froth. The disadvantage of this approach is the low yield of clean coal, but it is possible to recover more coal by re-treating the refuse by some other process. A further disadvantage is that froth-flotation is more expensive than other wet density processes used for coarser coal, not only because the process is itself more expensive but also because of the cost of removing water from finely ground coal particles.

All the wet density separation technologies require as a final step of the coal cleaning process, dewatering of the clean coal. The high cost of dewatering and drying has prompted a renewed interest in Dry

Separation processes. The commercially available techniques -- air jigs and air tables -- are, however, less efficient than wet methods. A number of new processes are under development, namely electrostatic and dry magnetic separation. Yet, dewatering is likely to continue to be necessary not only to increase the as received heating value of the clean coal but also to improve its handling characteristics (Mellanby-Lee, 1986).

There are inherent inefficiencies associated with all density separation processes which stem from the fact that organic and mineral matter are interlocked to some extent for all specific gravities and therefore the clean coal float will always contain some impurities and the reject sink fraction will contain some organic matter. These inefficiencies may reduce the effective yield of PCC technologies by as much as 49% (Morrison, 1981).

The best sulfur removal results using PCC are obtained for bituminous coals with high pyritic sulfur content (Northern Appalachian and Illinois Basin) for which 20-30% of total sulfur can be removed by physical means. An EPRI (1985) report on emissions controls indicates that cleaning of Illinois coal with a state-of-the-art technology (at a "level 4" preparation plant, i.e., a facility where all coal size fractions are cleaned) may achieve a 31.2% removal rate at 95% Btu recovery.

3. Chemical Coal Cleaning

In order to decrease the sulfur content of high sulfur coal to levels that can comply with SIP requirements it is usually necessary to treat the coal chemically to remove both organic and inorganic sulfur. At present, several chemical cleaning processes exist at a bench scale,

but none are available commercially. We will comment briefly on two of such techniques: TRW-Gravimelt, Solvent Refined Coal (SRC).

The TRW-Gravimelt is based on the extraction of sulfur from coal by a hot molten caustic compound. The coal is treated with a mixture of potassium and sodium hydroxides at a relatively low temperature (370°C) followed by washing with water. Results reported in Morrison (1981) (after Meyers and Hart, 1980) indicate that the treatment of a run-of-mine (.47Kg/GJ sulfur content) coal result in removal rates of 89% and 23% for pyritic and organic sulfur respectively. When the "treatment" was applied to the float product of a gravity separation technique, which contained very little pyritic sulfur, the resulting removal rate of organic sulfur was 82%. More recent work has achieved total sulfur removals of between 80% and 90%. Two kind of problems, which may affect the commercial use of this technology, have been reported. First, the removal process has significant energy losses. Second, handling of hot caustic solutions on a large scale present design and operational problems (Morrison, 1981).

Two Solvent Refined Coal processes have been developed: SRC-I and SRC-II. The difference is that SRC-I produces a solid product while the other upgrades the SRC-I product to coal liquids. The SRC-I product is useful for high quality coke production or as a binder in the manufacture of formed coke, as well as a low-sulfur boiler fuel. The SRC-II process can yield liquid products to be used as boiler and turbine fuels. Both processes are technologically similar. Pullen (1981) describes the general scheme: pulverized coal is slurried in a coal derived solvent; then it is pumped through a preheater and pressurized with hydrogen in

the reactor and then heated. After some time (40 minutes of residence) in the reactor the digest is cooled. Unreacted hydrogen, hydrocarbon gases, H_2S and water vapor are then removed. Solids separation and solvent regeneration can be achieved by means of a rotary drum or a leaf filter with vacuum distillation.

An SRC product burn test was performed at Georgia Power Company's Mitchell Plant in 1978. The reported results show that burning a SRC product (obtained from a 3.9% sulfur coal) meets by a wide margin the EPA emission standards for SO_2, NO_x and particles with no significant losses of boiler efficiency. Furthermore, the volume of fly and bottom ash was much smaller than when coal (.88% sulfur, 8.94% ash) was burned, thus keeping the boiler much cleaner. Also, the heating value was very high (15274 Btu/lb). Some handling problems, due to the friable nature of the SRC product, were reported. Studies have also pointed out the existence of problems associated with pulverizing SRC. However, with the modifications made in the pulverizers used in the test burn, no such problems were encountered.

To our knowledge there exist no estimates of the costs of sulfur removal by either TRW-Gravimelt or SRC processes.

4. Hydropyrolysis

Hydropyrolysis represents an intermediate solution between the complete gasification and liquefaction of coal and its use as a solid fuel. The process essentially involves the devolatilization of the coal under hydrogen pressure. The outputs of the hydropyrolysis of coal are: oil, high heating value gas, char and water. The char can be gasified to produce synthetic fuel but can also be burned in solid form in power

plants. Bhagwat and Johnson (1984) report that low temperature pyrolisis of Illinois #6 coal is expected to yield (in % wt. of dry coal): 60% char, 19% oil, 6% water and 15% gas. Also, Utah Power & Light conducted a project which attempted to demonstrate the commercial feasibility of producing by hydropyrolysis, .6 ton of char and 1.1 barrels of liquid petroleum by products from 1 ton of bituminous coal (Bullard, 1986).

Several hydropyrolysis methods have been developed, including: fixed bed reactors, fluidized bed reactors, entrained beds and heating by Joule effect. These are still at bench-scale and it is not clear which is the best. Also, detailed analyses of the chars produced are not widely available (c.f., Furfari, 1982). The results by hydropyrolysis are also quite disparate as to the nature and quantity of the sulfur eliminated. Some studies have obtained 85% removal of sulfur in a fluidized bed installation; others, treating 4.2% sulfur coal, have eliminated 74-84% of sulfur in the gases and estimate that all organic and half of the pyritic sulfur is eliminated in the course of hydropyrolysis. This last conjecture has been questioned by several authors that have obtained very modest removal rates. Studies reported in Furfari have obtained .31% and 1% sulfur chars by treating .85% and 1.7% sulfur coals (at 550^{o}C under 2Mpa and 560^{o}C under 2.1Mpa, respectively). It seems well established that the organic sulfur is the most difficult to eliminate. Furfari points out that the differences in reported removal rates are caused more by the way in which the organic sulfur is bonded in the coal molecule and by the nature of the mineral matter than by differences in the hydropyrolysis parameters. It appears that char production is not by itself a desulfurization alternative. Indeed the char obtained from a high sulfur

coal will contain only a slightly lower sulfur content than the original coal. However, as Bullard (1986) remarks, detailed analysis of the charring process can identify the states in which the sulfur could be chemically attacked.

The marketability of char has been a controversial issue. Following work by Black and Veatch (1983), Bhagwat and Johnson (1984) list some potential risks associated with char combustion. One of the major problems is char's reported poor reactivity. If this is so, char's combustion requires very small particles and high ignition temperature, and particle residence time may not be enough for relatively complete burnout. This will create problems with pulverizers and precipitators. Also, poor reactivity creates flame stability problems and explosion hazards. However, as Bhagwat points out, many bench-scale tests with chars obtained from different processes have shown sufficient reactivity to be used as a boiler fuel. Also commercial companies do actually burn coke, which is a lower grade fuel than char. The main question regarding the commercial potential of char is whether successful desulfurization of char is economically possible or not. At present, no commercial process for the production of compliance char exists. Bullard (1986) suggests that even if desulfurization of char proves infeasible, there is reason to believe that char itself could be superior to coal for use in fluidized bed combustors.

D. CONCLUSIONS

This chapter reviews some of the major technological alternatives for precombustion control of sulfur emissions from coal combustion: coal

blending and switching, Wet Density Separation technologies, TRW-Gravimelt process, Solvent Refined Coal processes and Hydropyrolysis. Comparison of their relative strengths and weaknesses proved to be difficult since those processes are at quite different stages of development.

Coal blending and separation techniques are widely used in the industry. Their commercial and sulfur removal potential are thus well documented. The major limitation of these alternatives is that they can only remove inorganic sulfur which is usually not sufficient to decrease the sulfur content of high sulfur coals to compliance levels.

To achieve removal rates that can comply with the SIP requirements it may be necessary to treat the coal chemically to remove both organic and inorganic sulfur. Production of char by hydropyrolysis is another alternative undergoing development, even though it is not, by itself, a desulfurization technique. However, analysis of the charring process can identify the states in which the sulfur can be chemically attacked. Chemical cleaning and char production technologies are in most cases at a bench-level, and detailed analyses of the fuels produced are not widely available. Most of those fuels have not yet been test burned and information on their commercial potential is almost nonexistent.

CHAPTER IV. COAL QUALITY, POWER GENERATION AND COAL PROCUREMENT PRACTICE

A. INTRODUCTION

Coal quality is an important factor in coal procurement decisions. The modest decision rule of minimizing delivered cents per million Btu has given way to analysis of coal quality characteristics in engineering models of operating systems to assess a prospective coal's impact on the heat rate, capacity, availability, maintenance and emissions of a coal-fired electric generating station. Procurement practices typically specify the levels of a number of key coal quality characteristics with known correlations to the operating performance of the plant. Adjustments for deviations from design characteristics are made by coal blending, capacity derating and equipment retrofit.

This chapter serves two purposes. First, we review the impact of coal quality on coal procurement practice in general. Second we report on a survey of coal procurement requirements, conducted for this project, at a number of coal fired power plants in the east and midwest. As part of our survey, we requested information on the coal procurement specifications of our respondent generating stations. Most stations issue specifications for a long list of coal quality characteristics.

B. IMPORTANT FACTORS IN COAL PROCUREMENT DECISIONS

Changes in the technological, regulatory and economic environment of coal-fired power generation during the last quarter century have transformed the focus of coal procurement from delivered price to explicit consideration of the total busbar cost of electricity generation. The

total busbar cost is determined by the coal quality and the delivered price given the embedded plant technology. For example, a lower quality coal may have a cheaper delivered price per million Btu but may degrade plant performance to the point that the busbar cost increases over a higher delivered price alternative. Fuel procurement procedures at most utilities now require analysis of coal quality characteristics and their impact on the total busbar cost of power generation. Utilities no longer purchase fuel solely on the basis of least delivered price.[6]

Utilities compare fuel cost in mills/kwh (which embodies the generating efficiency of the fuel), and the boiler efficiency of the fuel. Other factors are the uncommitted reserves of the producer, the producer's proven production capacity and his ability to load suitable transportation for the coal. The effect of the fuel charge on the capacity and capability of the generating unit are more important as construction costs for new units soar. Fuel purchasers also consider the coals' blending potential, grindability and handling characteristics. For example, a utility expects to know whether a blend's ash fusion temperature is significantly lower than either of its constituent coals when blending for a reduced sulfur product.[7]

Coal quality affects the total production cost of electricity in plant design and construction, in operation and maintenance, even the availability and operating life of the plant. For example, coal quality affects the construction costs since lower rank coals require larger

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[6] Coal Week (6/11/84), "Coal Quality and Service Becoming as Important as Price," p.1.

[7] Ibid.

furnaces than higher rank coals to accommodate the larger fuel charges needed to achieve a given generating capacity. They also require larger storage, handling and pulverizing capacities. High ash and low volatile coals require expensive downshot firing configurations rather than the more conventional horizontally or tangentially fired furnaces.[8] After the plant is constructed, coal quality impacts the heat rate and capacity of the plant, as well as availability and maintenance costs.[9] Higher heating values lower the heat rate and increase the capacity of the plant. Coals with high ash fouling potential reduce availability of the plant and increase maintenance costs.

C. TECHNICAL SIGNIFICANCE OF COAL CHARACTERISTICS

Coal is a heterogeneous commodity. We think of heterogeneity as a bundle of attributes which affect the cost and operating efficiency of a coal fired power generating station. Coal quality is a measurable set of characteristics to which we can attribute cost and operating effects on the generating station. The basic set of quality characteristics are sulfur, ash, BTU, moisture and volatile content of the coal, the chemical and mineral composition of the ash, and the grindability of the coal. Variations in each of these characteristics have cost ramifications throughout the various operating systems that comprise a coal fired power generating station. The utilities' principal concern is the effect of

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[8] Mellanby-Lee (1986), p. 20.

[9] Coal Week (4/7/86), "EPRI Cites Need for Better Data on Coal Quality and Boiler Costs," p.6.

variation in coal quality on heat rate, capacity, availability and maintenance.[10]

Sulfur content of the coal affects boiler efficiency by influencing the slagging potential of the coal. It is also a principal contributor to low and high temperature corrosion of auxiliary equipment. Sulfur and nitrogen are the primary culprits targeted by flue gas emissions regulation. Apparatus to remove these contaminants from stack gases consumes generated energy thus reducing the net capacity of the plant. Disposal of the by-products of flue gas desulfurization can be expensive.[11] Finally, sulfur content of the flue gas affects the fly ash collection efficiency of cold side electrostatic precipitators by altering the resistivity of the fly ash particles.

Ash content of the coal affects all phases of plant operation and maintenance, including coal handling, pulverizing, combustion, air and flue gas handling, ash handling, and the steam generation and turbine cycles. Higher raw ash content: decreases the heating value per unit weight of the coal; increases pulverizer wear; decreases pulverized coal fineness causing increased carbon loss and slagging potential; increases ash deposition on furnace and convective pass surfaces which if beyond design levels amplifies slagging and fouling problems; increases heat transfer by augmenting emissivity of the fuel charge mass; decreases heat transfer by elevating absorbtion and scattering; and generally increases the heat rate of the unit. Changing the chemical and mineral composition

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[10] EPRI (1986) is the primary source for most of the technical information in this section.

[11] It should be noted that some FGD technologies produce a salable sulfur by-product. Others produce a sludge with nasty disposal characteristics.

of the ash causes: wide variation in slagging and fouling tendencies of the coal; fluctuations in the carbon utilization efficiency of the boiler; modification of the fineness of pulverization; changes in absorbtion and scattering; alteration of ash fusion temperatures causing variation in the propensity to low temperature slagging.

The BTU content of coal measures the heating value of the coal. Higher heating value coal reduces the transportation and handling costs of coal per calorific value by weight; decreases the duty cycle for coal handling equipment; increases the firing time of fixed storage capacity; and increases boiler efficiency for a fixed fuel charge.

The moisture content of coal influences the performance of many components of the steam generation system. High moisture levels exacerbate freezing problems and coal deterioration concerns. High moisture also creates many handling problems simply by increasing the adhesion of fine coal particles to handling equipment. It tends to increase pulverizer capacity by increasing the grindability of the coal. Moisture adversely affects the efficiency of the combustion cycle by increasing combustion heat loss, flue gas thermal loss and reducing convective heat transfer. It also reduces electrostatic precipitator performance by reducing the surface resistivity of the fly ash particles.

The volatile content of the coal influences fuel ignition, flame stability and length, and char reactivity. Higher volatile content is correlated with higher char reactivity which induces higher carbon burnout, increasing boiler efficiency. This also lowers the carbon content of the ash, inducing higher ash resistivity, and lowers the necessary pulverized feed product fineness increasing pulverizer capacity and

reducing the forced draft flowrate. Lower volatile content can require oil injection to assure ignition and flame stability. It may also reduce char reactivity and carbon burnout which induces higher fuel flowrate, higher ash carbon content and lower ash resistivity.

Other characteristics which utilities often specify are: fixed carbon content; friability, size consist or dispersion and density of the feed coal; chlorine, sodium, nitrogen, hydrogen, oxygen and calcium levels in the ash; grindability; ash fusion temperature, reducing or oxidizing; ash resistivity; and base-acid ratios of the ash.

D. MITIGATING OPERATIONAL IMPACTS OF HETEROGENEOUS COAL PRODUCTS

Regulatory constraints on sulfur and nitrogen emissions are prompting some utilities to replace coals that have a preferred set of attributes with coals that have a differing set of attributes. These alternative fuels have qualities that are desirable for regulatory compliance. However utilities may regard the alternative fuels as distinctly inferior to their current burn when the alternative's total set of attributes is evaluated. This creates technical problems with steam generation for which there exist no easy or cheap solutions. Utilities in this situation generally use three techniques to adjust their embedded technology to the new regulatory environment. These techniques are coal blending, capacity derating and equipment retrofitting.

Coal blending is often the least costly choice. Specific targets for sulfur and nitrogen emissions can be met by blending low sulfur or low nitrogen fuel with the current burn. Blends must be test burned

since it is extremely difficult to predict their performance.[12] Sometimes any blend that meets the regulatory constraint requires that the generating units be derated. Derating expresses the reduction in generating capacity caused by substitution of a coal with heat content below the boiler's design specifications for a fuel. Fuel blending can result in significant operating inefficiencies in a generating system even though only a few key parameters of coal quality may be changed, particularly moisture, handling characteristics, heating value and ash chemistry.

Retrofitting is the most drastic alternative, and usually the most expensive. Plants may be retrofitted to insure regulatory compliance and availability of generating capacity given restricted fuel choices in the pre-combustion, combustion and post-combustion phases of the steam generation cycle. Retrofitting changes the stations' embedded technology. It requires large capital outlays for new equipment. It usually requires the station be shut down for an extended period of time. The cost of lost availability alone may be the most expensive factor in retrofitting.

In general, coal-fired power generating stations are designed to operate using coal with a specified range of coal qualities. Deviations from the specification set are costly to the utility in terms of operat-

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[12] Not all characteristics have what one may call the convexity property, i.e., blending two fuels with different levels of a quality characteristic results in a fuel with an "average" level of the characteristic. Blending works well with sulfur content, raw ash content and moisture content. However, one cannot combine high and low ash fusion temperature coals and obtain an "average" ash fusion temperature coal. Grindability cannot be blended either. The blending potential for volatility is unknown to us. Some volatility blending occurs in coking, but we do not known how well it works for combustion.

ing efficiency and generating capacity. Coal procurement policies at most utilities explicitly recognize these facts. Often the lowest delivered price bid is not the fuel buyers' choice. Rather coals that minimize the total cost of power generation, including emissions compliance, are chosen.

E. COAL PROCUREMENT FOR HETEROGENEOUS COAL PRODUCTS

The usual coal procurement practice is to issue a set of specifications for coal quality consisting of ranges of acceptable values for coal attributes as measured by standardized tests, and a set of specifications concerning quantity and delivery conditions. The suppliers bid by price and quality, offering coals whose attributes are within the specification ranges. Suppliers are usually required to prove the fuels can meet specifications by submitting samples to testing agencies. Uncertainty about the performance of a fuel is resolved by evaluating a test burn of the fuel at the station during off-peak demand periods. Test burns explicitly evaluate the effect of a specific coal on the total cost of electricity production.

F. COAL PROCUREMENT SPECIFICATIONS IN THE SURVEY

As discussed in more detail in chapter VI, a detailed questionnaire was sent to a sample of coal-fired electric generating stations in the east and midwest. Page 2 of the survey was designed to gather information on the procurement specifications applied by the coal-fired generating stations in the sample (see Appendix A). In order to evaluate the probability of successfully marketing a reduced sulfur coal product, we must

know the specifications used by the utilities as part of their procurement decision. This enables us to measure how far utility buyers are willing to deviate from current specifications when they make an actual procurement decision. For example, this is particularly important in the context of a utility's willingness to purchase a low volatile reduced sulfur product. We were primarily interested in the frequency a coal quality characteristic is used by the sample as an indication of that specification's importance to the sample. We were secondarily interested in the range of values of coal quality characteristics in the specifications used by the sample. The range of values should demonstrate that our sample was not a biased draw from the population of coal-fired generating stations. The list of specifications surveyed and the aggregate responses are recorded in Table 4-I.[13] Note that minimum BTU, volatility and grindability levels and maximum sulfur, moisture, raw ash content and size dispersion levels are specified by at least three-quarters (3/4) of our respondents. Over one-half (1/2) additionally specified a minimum ash fusion temperature. These were principally dry-bottom plants. The smaller group of wet-bottom plants specified maximum ash fusion temperatures. More than a third (1/3) of the respondents reported specifications on ash chemistry. The range of specifications indicated the sample utilities purchased coal from the Powder River Basin, from the midwest region including the Illinois Basin, and from the Appalachian Region. This indicates that Illinois Basin coal competes with the other major coal producing regions.

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[13] Ash resistivity and fouling and slagging indices were not aggregated. The range and variation of responses rendered aggregation meaningless. We list only the frequency of specification.

The range of responses to a given specification gives us information on the distribution of the value of the specification in our sample. It is helpful to know whether, for example, volatility specifications are evenly dispersed through wide range of levels, or whether most specifications are concentrated in a narrow range of values. We plotted a frequency distribution (histogram) of the volatility responses on a unit basis (Figure 4-1). Clearly, the vast majority of volatility specifications are concentrated in the 30%-39% range. Only a handful of generating stations operate with coals with less than 30% volatility.

Clearly in our sample, coal quality characteristics are closely watched. In fact only one utility reported basing procurement decisions on delivered price alone. Coal quality specifications beyond BTU, ash and moisture have become the industry norm in procurement practice. The operators of coal-fired steam generating stations are concerned about how well a particular coal will perform in their furnace and how the fuel's performance will affect operating capacity of the station. To measure the expected performance, utilities rely on engineering correlations between coal quality characteristics and performance parameters for their particular generating station. Using the engineering models with the measured coal quality characteristics allows the utility to estimate the effect on heat rate, capacity, availability and maintenance of a procurement decision. When a coal product is sufficiently unknown, but appears to be satisfactory from the model, a test burn is usually required to confirm the engineering model's results. Thus procurement decisions are no longer made on the basis of delivered price per million BTU by most

utilities. Coal quality characteristics have a fundamental impact on procurement decisions.

G. CONCLUSION

Many coal quality characteristics influence coal procurement decisions. Utilities desire to predict a prospective coal's impact on heat rate, capacity, availability and maintenance of the coal-fired electric power generating. Responses to our survey indicated that the utilities in our sample consider a wide range of coal quality characteristics in their coal procurement decisions.

Fig. IV-1: VOLATILITY HISTOGRAM

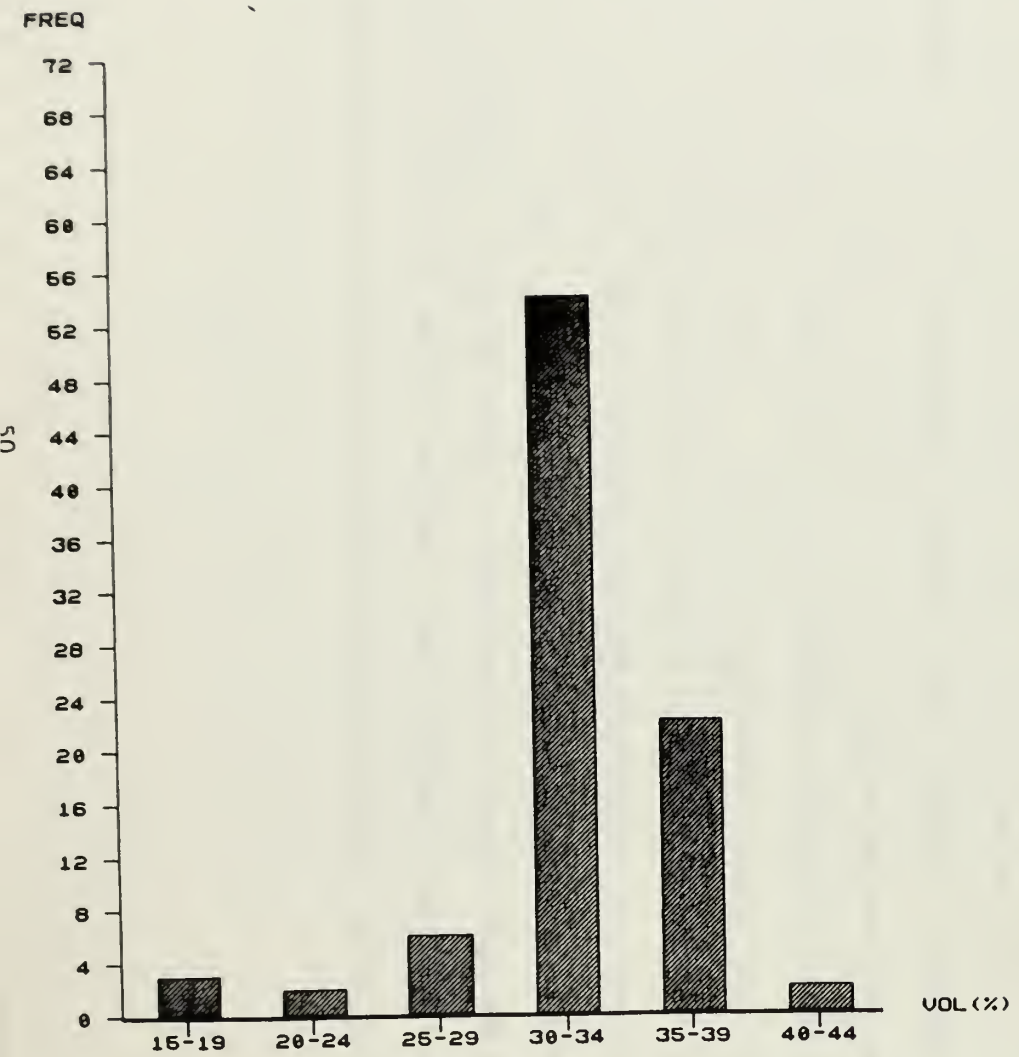

TABLE 4-I

Specification	Number	Mean	Min	Max
(a) Minimum BTU/lb (moisture free)	55	11450	7700	13889
(b) Maximum Sulfur Content (as received, measured lb/MMbtu)	61	2.5	0.59	6.8
(c) Maximum Moisture Content (as received %)	61	16%	6%	36%
(d) Minimum Volatile Matter (by weight, moisture free)	48	32%	19%	44%
(e) Maximum Chlorine (by weight, moisture free)	28	0.21%	0.03%	0.50%
(f) Size Dispersion (Maximum % < 1/4")	44	41%	3%	85%
(g) Minimum Hargrove Grindability Index	54	49	40	63
(h) Maximum Ash Content (by weight, moisture free)	59	12%	6%	33%
(i) Minimum T_{250} (ash fusion) Temperature (^{o}F)	40	2174	1900	2660
(j) Maximum T_{250} (Ash fusion) Temperature (^{o}F)	25	2500	2100	2920
(k) Minimum Ash Resistivity (ohms/cm)	16	***	***	***
(l) Maximum Base/Acid Ratio of Ash	17	0.64	0.25	2.33
(m) Maximum Fouling Index Computed Using $Na_2O - K_2O$	16	***	***	***
(n) Maximum Na_2O as % of Ash Mineral Analysis	23	1.34	0.40	3.0
(o) Maximum % Alkaline as Na_2O, Dry Basis	8	0.32	0.09	0.65
(p) Maximum Slagging Index	16	***	***	***

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CHAPTER V. FUEL QUALITY PREFERENCES FROM MARKET DATA

A. INTRODUCTION

As was discussed in Chapter II, since the passage of the 1970 Clean Air Act there has been a considerable shift in demand away from high-sulfur coal toward low-sulfur coal. Coal consumers have frequently been willing to pay a premium for low-sulfur coal over high-sulfur coal. The premium is bounded, of course, since the undesirability of sulfur varies from consumer to consumer, due to differences in applicable environmental regulations and because of technologies are available for reducing the sulfur content of coal or reducing emissions from the combustion of coal. Estimating the magnitude of the sulfur premium is the main purpose of this study. This premium can be interpreted as the increased price desulfurized coal could bring in the marketplace. In this study we take several approaches to measuring this premium.

In this chapter we attempt to infer the sulfur premium based on observed purchases of coal by utilities. By examining individual fuel purchases and statistically comparing low-sulfur and high-sulfur purchases, accounting for everything but sulfur content, we can infer the sulfur premium.

More specifically, using a hedonic price technique, a price function is statistically estimated for coal as a function of coal quality (sulfur, ash and thermal content) and location in Illinois. The marginal valuation placed on sulfur is inferred from the results. The statistical analysis is based on transactions-level data on Illinois utility purchases of coal in 1985. Thus we focus on all purchases within Illinois,

including purchases of Illinois coal and coal from other states. In the next section, the theory behind measurement of the hedonic price function is developed. The subsequent two sections cover the estimation of the price function and the interpretation of the results, including the sulfur penalty. Conclusions and R&D implications follow.

B. THEORY

The theoretical development is in two parts. First, it is assumed that there is a spatially homogeneous market where transportation costs are irrelevant. The framework is then extended to include geography, recognizing the fact that spatially adjacent markets face different but connected price regimes.

1. Single Spaceless Market

Consider a single market in which multiple grades of coal are available. Further, consider a single transaction for coal. The purchased coal is a bundle of characteristics, some undesirable (i.e., bads) $Z = (Z_1,\ldots, Z_n)$, and others desirable (goods) $H = (H_1,\ldots,H_m)$. For instance, Z_i might be the total quantity of sulfur or the total quantity of ash in the purchase; H_i might be the total heat content. The point is, these goods and bads are packaged together and can't readily be separated. Denote the transaction value $V(Z,H)$. It is plausible to assume first-degree homogeneity of V; i.e. twice as many Btu's, tons and raw sulfur should cost twice as much. If V is homogenous of degree one, a numeraire, H_m, can be chosen and V can be rewritten as

$$V(Z,H) = H_m \rho(z,h) \qquad (5\text{-}1a)$$

$$\text{where } z_i = Z_i/H_m \tag{5-1b}$$

$$h_i = H_i/H_m \tag{5-1c}$$

For example, if H_m is pounds of coal and Z_i is pounds of sulfur, then z_i is the weight fraction of sulfur and ρ is the price per pound of coal with characteristics (z,h). Writing V as ρ allows us to talk of a price per ton rather than value per shipment of varying size.

$\rho(z,h)$ is an hedonic price function, giving the price of coal equilibrium as a function of its attributes. The formation of ρ can be understood using the arguments of Rosen (1974). Each coal producing firm (i) has a set of iso-profit lines $O_i(z,h,\bar{\pi})$ indicating the coal price (as a function of z and h) which is necessary to achieve profit level $\bar{\pi}$. We may term these offer curves. Similarly, each coal consumer (j) has a set of bid curves, $\phi_j(z,h,\hat{\pi})$, indicating willingness to pay for coal of quality (z,h) to assure a profit level $\hat{\pi}$. Equilibrium among producers and consumers results in a market price as a function of quality, $\rho(z,h)$.

As is customary in hedonic analysis, in the case of coal, characteristics cannot be "untied." For example, one ton of coal with 1% sulfur is generally not the same as two half tons of coal with 1/2% sulfur. However, by mixing, they can be "repackaged." A ton of 1/2% sulfur coal can be blended with a ton of 1% sulfur coal to yield two tons of 3/4% sulfur coal. It is easy to see that repackaging implies $\rho(z,h)$ is convex. Further, because each z_i is undesirable (or at least not desirable), $\rho(z,h)$ must be monotonically non-increasing in each z_i.

Similarly, $\rho(z,h)$ must be monotonically non-decreasing in each h_i. A hypothetical set of offer, bid and price curves is shown in Fig. 5-1 (as a function of a single bad). Tangencies indicate equilibrium quality and price levels each firm will sell or consume.

Assuming $\rho(z,h)$ has been estimated and thus $V(Z,H)$ is known, the question is, what implicit prices are being placed on each of the characteristics of the coal? The marginal implicit price placed on any characteristic is the increase in expenditures associated with an incremental increase in the quantity of the characteristic:

$$u_i = \frac{\partial V}{\partial Z_i} = \frac{\partial \rho}{\partial z_i}, \tag{5-2a}$$

$$v_i = \frac{\partial V}{\partial H_i} = \begin{cases} \dfrac{\partial \rho}{\partial h_i} & \text{for } i < m \\ \rho(z,h) - \dfrac{1}{H_m}\left[\sum_i Z_i u_i + \sum_{i<m} v_i H_i\right], & \text{for } i = m. \end{cases} \tag{5-2b}$$

Because of homogeneity of V (or from 2b),

$$\sum_i u_i Z_i + \sum_i v_i H_i = V = H_m \rho(z,h) \tag{5-3}$$

Thus the implicit expenditures on each characteristic sum precisely to total expenditures. Of course, $u_i \leq 0$ and $v_i \geq 0$ since u_i is the "price" of a bad and v_i is the "price" of a good.

If someone is purchasing a bundle of goods and bads, then the more of a bad purchased, the lower the price, as is shown in Fig. 5-1. The hedonic price of a bad represents a "bribe" or compensation for agreeing to take the bad along with the good. For instance, the thermal value of the coal may be $2 per million Btu. By agreeing to take a unit of

troublesome sulfur (1 lb. S/MMBtu) along with a unit of heat, at a price of $0.50, one pays only $1.50 per million Btu. Convexity of the price function results in the absolute (unit) price of sulfur diminishing as the quantity of sulfur increases. Of course the price function is not the demand function. We do not know how much coal the market will take, even if the price is on the price function.

2. Spatial Markets

Because a significant fraction of the delivered price of coal can consist of transportation costs, an issue arises as to how one defines a single market for coal. Clearly if many consumers are located at the same spot, then a spaceless market exists. However, the more common situation is that consumers are scattered through space as are producers. Each consumer faces a different hedonic price function as each is a different distance from the array of producers and thus faces a different delivered price for the product of each producer.

Space can be treated by including in the hedonic price functions variables reflecting the location of the consumers $X=(x_1,x_2)$. Thus the transaction value becomes $V(Z,H,X)$ and the hedonic price function becomes $\rho(z,h,X)$. The difference in price (ρ) between locations i and j is bounded by the transport cost between i and j which is obviously a function of the distance between the locations. This suggests correlated residuals which must be taken into account when estimating the price function in order to improve efficiency (see Cliff and Ord, 1981). The results presented here are preliminary in large part because the interaction of prices at various locations have been neglected.

C. ESTIMATING THE HEDONIC PRICE FUNCTION

Thermal content is the coal characteristic consumers most desire while ash and sulfur content are generally undesirable. Sulfur is undesirable because its emissions are subject to control. Ash is undesirable because of controls on emissions of flyash but probably more importantly because ash can degrade the performance and/or shorten the life of boilers, crushers and other coal-handling equipment at a generating station. Furthermore, ash must be disposed of after combustion, at some cost. Ash has some desirable qualities including increasing the conductivity of the flue-gas stream and improving the distribution of heat within a boiler. Thus ash is ambiguously a good or a bad, although it is hypothesized here to be undesirable on balance.

1. The Sample

Data on coal purchases by Illinois electric utilities in 1985 were used to estimate a hedonic price function for coal. The Federal Energy Regulatory Commission (FERC) collects monthly data (on FERC Form 423) from utilities on coal purchases by each generating station. Each purchase is detailed, giving quantity purchased, certain quality characteristics (sulfur, ash, thermal content), delivered price and the identity of the power plant receiving the fuel. Latitude and longitude data for each of these consumers was extracted from Energy Information Administration Form 767 and merged with the Form 423 data. Based on these data, we have developed a data base of all coal purchases by utilities in the United States from 1970--1986. From this data set, we extracted information on 1985 purchases in Illinois. The resulting data set contains 644 observations, consisting of prices paid, the indicated coal

characteristics, and the location of the purchaser. Table 5-I shows a portion of the sample.

Table 5-II shows some descriptive statistics for the sample. Note that the average price for Illinois coal purchases in 1985 was $1.91 per million Btu with a large standard deviation and a wide range of prices, ranging from $0.41 to $3.84 per million Btu. The latter price was undoubtedly for western low-sulfur coal, a product which has become very expensive in Illinois due to contracts signed some years ago, before coal prices declined. The sulfur content of 1985 purchases averaged 1.79 pounds per million Btu, also with a large variance. Some coal in the sample had a fairly high ash content. Also shown in the table are the correlation coefficients for price, sulfur and ash. As expected, price is highly negatively correlated with sulfur and ash. Ash and sulfur are positively correlated, suggesting that they tend to be found together.

2. The Estimation

Assume that the transaction function $V(S,A,H,X_1,X_2)$ is homogeneous of degree 1 in S, A and H, so the analysis is in terms of the price function ρ. The variables x_1 and x_2 refer to latitude and longitude respectively, of the purchasers. A quadratic functional form is used so that convexity can be made to apply globally. Thus the price function has the following form:

$$\rho(s,a,x_1,x_2) = (1\ z)\alpha + \tfrac{1}{2}z\beta z' \qquad (5\text{-}4)$$

where $z = (s,a,x_1,x_2)$ and the vector α and matrix β contain coefficients

to be estimated. This implies that the implicit prices of sulfur (s), ash (a), and thermal content (h) from equation 5-2 are given by

$$u_s = \alpha_s + \beta_{ss}s + \beta_{sa}a + \beta_{sx1}x1 + \beta_{sx2}x2 \qquad (5\text{-}5a)$$

$$u_a = \alpha 1_\alpha + \beta_{aa}a + \beta_{sa}s + \beta_{ax1}x1 + \beta_{ax2}x2 \qquad (5\text{-}5b)$$

$$h = \rho - u_s s - u_a a \qquad (5\text{-}5c)$$

Convexity of ρ requires that β be positive semidefinite. Monotonicity can not be improved globally; however, at ash and sulfur content equal to zero, monotonicity implies that $\alpha_i \geq 0$, for i=s,a. Convexity gives $\beta_{ii} \geq 0$ (for i=s,a) but it is still possible for $u_i > 0$ if $\beta_{sa} << 0$.

Equation (5-4) was estimated using ordinary least squares weighted by output in tons to correct for heteroskedasticity. Results of the estimation for Illinois deliveries in 1985 are presented in Table 5-III. Imposition of convexity resulted in two of the coefficients being identically zero (the second order ash term and the sulfur-ash cross term). The R^2 for the estimation is 0.87, which is reasonably good. Most of the remaining error is probably due either to the use of a second order approximation or more likely to the presence of long-term contracts, particularly for low-sulfur coal, contracts which in the present market involve exceptionally high prices. The Durbin-Watson statistic is 1.80 suggesting that some spatial autocorrelation may be present.

D. RESULTS

To interpret the results, recall that the latitude of Illinois ranges from approximately 37° to 42° north and longitude ranges from 87° to 94° west. It is clear from Table 5-III that at low ash and sulfur levels (for example, zero values), the price of coal tends to be slightly higher the further north in the state one goes, a reasonable result because most mines are in central and southern Illinois. In addition, coal prices from the price function are lower in eastern Illinois. It can also be seen that the price of sulfur (eqn. 5-5a) is negative, as it should be, and decreases in absolute value as sulfur content increases.

The response of coal price to sulfur level can be seen more clearly in Figure 5-2. In the figure, the price of coal is plotted, as a function of sulfur level, for the mean ash value (8.8 pounds per million Btu) for coal purchased in central Illinois (latitude, 40°, longitude, 88°).

The slope of a line at a particular point represents the price of sulfur, the permit "bribe" referred to earlier, necessary to induce consumers to take the sulfur along with the thermal value. For instance, central Illinois coal with no sulfur would sell for $3.90 per million Btu (MMBtu). Coal with 1 lb. of sulfur per million Btu would sell for $2.73 per MMBtu with a sulfur penalty of $1.04 per MMBtu. This implies that the price of the thermal content of the 1 lb. sulfur coal is $3.77/MMBtu. When the consumer buys the 1 lb. sulfur coal, he pays $3.77 but gets a discount of $1.04 for the sulfur he takes as well. Coal with 2 lbs. sulfur per million Btu goes for $1.82 per million Btu, with a sulfur price of -$0.78MMBtu/lbs/MMBtu per pound of sulfur per million Btu, resulting in a fuel price of $3.38 per million Btu. Ash has been

neglected in this discussion (but not in the figure or estimated equation), so these numbers are not quite accurate.[14]

In terms of the sulfur penalty, the price of sulfur can be interpreted as the marginal payoff to the producer from reducing sulfur; alternately, it can be interpreted as the incentive to the consumer to take higher sulfur. Thus a sulfur price of -$0.78/MMBtu/lb.S/MMBtu implies that for a reduction in the sulfur content by 1 pound per million Btu., the price can be raised by 78¢, and still be competitive. For a 12,000 Btu per pound coal, this translates to roughly $19 per ton. As is shown in the figure, the higher the sulfur level, the lower is the sulfur price in absolute terms. This is a result of the convexity assumption.

E. CONCLUSIONS

The results presented in this chapter reflect the power of using hedonic techniques to measure the sulfur premium in coal. The results are qualitatively in agreement with intuition about how the coal market operates in Illinois. However, this approach has only been explored in a rudimentary way here. Unresolved questions concern the treatment of coal contracts, the proper treatment of space, including the possibility of arbitrage between locations, and the spatial autocorrelation of errors. These issues are being explored in current research.

The implications of this work for desulfurization R & D are significant. The preliminary results in Figure 5-2 show that a premium of as much as $1.30/MMBtu per pound of sulfur per million Btu may be sup-

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[14]Another inaccuracy is that the unit sulfur penalty changes with sulfur level so that total sulfur penalty can only accurately be obtained by integration.

ported by the market. Further research is needed to refine these results as well as to develop results for other coal characteristics.

Figure 5-1: Equilibrium Hedonic Prices

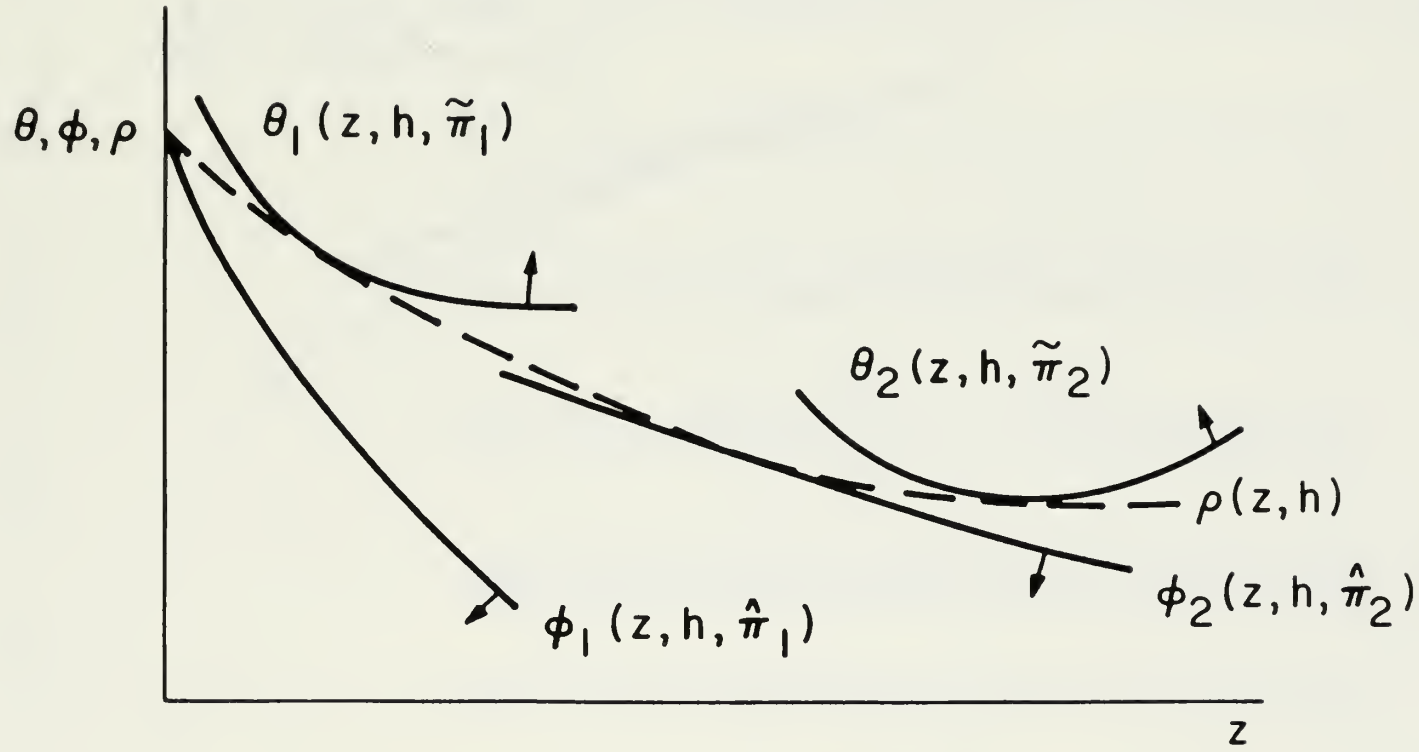

Figure 5-2: Hedonic Price Function, Central Illinois (Ash = 8.8 lb/10^6 Btu)

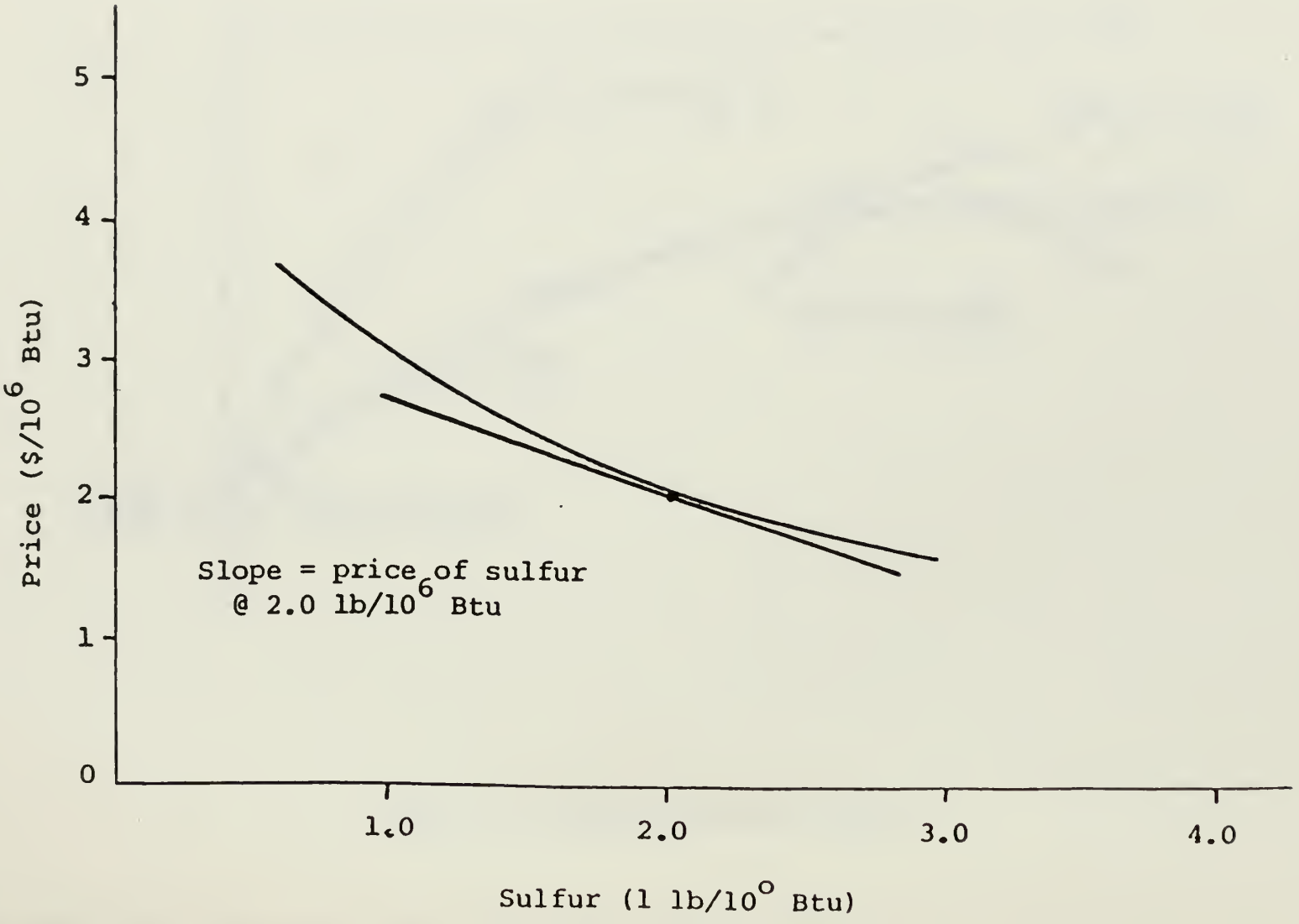

TABLE 5-I: SAMPLE OF THE MARKET DATA USED FOR HEDONIC ESTIMATION.

PLANT Code	COST (cents/ MMBtu)	SULFUR (%)	ASH (%)	QUANTITY (TONS)	BTU per pound	STATE (---	LATITUDE of consumer	LONGITUDE ---)
0056	187.80	1.06	12.23	15835	11540	01	31.48749	87.91249
0056	194.60	1.24	12.49	17851	11893	01	31.48749	87.91249
0007	137.40	1.54	11.00	1740	12711	01	34.01361	85.97028
0007	209.60	1.64	13.10	20247	11878	01	34.01361	85.97028
0008	194.40	1.84	8.90	4969	12574	01	33.64417	88.19722
0008	239.80	1.22	11.50	30103	12251	01	33.64417	88.19722
0010	154.10	1.09	14.00	9881	11893	01	32.59999	87.76666
0010	158.50	1.26	17.50	12096	11619	01	32.59999	87.76666
0026	205.20	1.25	14.20	62362	11877	01	33.24277	86.45888
0026	184.00	.86	14.10	82883	10908	01	33.24277	86.45888
6002	298.30	.68	11.70	80201	12222	01	33.63194	87.05971
6002	251.90	.50	10.80	84531	12702	01	33.63194	87.05971
1122	204.00	1.02	8.20	600	10000	19	42.02472	93.60638
1122	198.00	.45	6.50	5900	8024	19	42.02472	93.60638
6009	163.80	.19	4.60	44625	8659	05	34.42360	92.13916
6009	165.20	.40	6.00	339529	8725	05	34.42360	92.13916
6641	153.70	.21	5.20	367348	8699	05	35.67332	91.40833
6641	160.00	.38	6.00	73379	8737	05	35.67332	91.40833
2167	150.00	3.23	10.40	89867	10740	29	36.51582	89.56471
2167	150.00	3.24	10.40	31300	11689	29	36.51582	89.56471
2168	208.60	4.28	11.50	113500	10317	29	39.54805	92.63611
2168	146.80	4.17	11.20	50500	10550	29	39.54805	92.63611
2384	214.20	.83	8.80	467	12968	34	39.68304	75.52415
2384	214.20	.83	8.80	233	12968	34	39.68304	75.52415
1552	172.00	2.01	8.20	21000	13033	24	39.32332	76.36665
1554	207.60	.99	7.60	7333	13030	24	39.17776	76.53333
1554	207.60	.99	7.60	14667	13030	24	39.17776	76.53333
1381	118.00	2.52	13.50	6100	11016	21	37.96361	86.79027
1381	146.00	2.49	9.70	21000	11015	21	37.96361	86.79027

TABLE 5-II: Descriptive statistics, Illinois utility coal purchases, 1985

Statistic	Parameter		
	Price (¢ per 10^6 Btu)	Sulfur (lb. per 10^6 Btu)	Ash (lb. per 10^6 Btu)
Mean	191.1	1.80	8.787
Std. Error	80.0	1.04	4.281
Minimum	41.4	0.33	3.383
Maximum	384.0	4.47	42.787
	Correlation Coefficients		
r_{sp}		-0.66456	
r_{ap}		-0.50784	
r_{as}		0.51521	

TABLE 5-III: Estimated Coefficients, Illinois (Eqn. 5-4)

Variable	Estimate	Standard Error	Asymptotic t-statistic
α_0	-44175.0	36974.0	-1.1948
α_s	-2078.2	256.45	-8.1036
α_a	158.72	111.66	1.4215
α_{X1}	-684.77	284.73	-2.4050
α_{X2}	1330.7	734.22	1.8124
β_{ss}	13.444	2.2370	6.0097
β_{sa}	0.	0.	
β_{aa}	0.	0.	
β_{sX1}	-15.768	1.9995	-7.8864
β_{sX2}	29.29	2.8602	10.241
β_{aX1}	4.2719	0.4614	9.2581
β_{aX2}	-3.6391	1.2019	-3.0277
β_{X1X1}	-0.99626	0.99019	-1.0061
β_{X1X2}	8.6643	2.8459	3.0445
$\beta 1_{X2X2}$	-9.5727	3.7220	-2.5719

CHAPTER VI. FUEL QUALITY PREFERENCES BASED ON SURVEY INFORMATION

A. INTRODUCTION

From an economic point of view, utilities' preferences for fuel attributes are reflected in the prices they are willing to pay for different bundles of those characteristics, i.e. for fuels of different quality. Thus, fuel transactions convey information on the unobservable preferences.

There are two major ways by which that information can be elicited. One, explored in Chapter V, is based on actual market transactions. Here we will develop an alternative approach based on directly asking utilities how much are they willing to buy, at a given price, of a fuel with a given set of attributes. By varying attributes and prices over the sample, we generate a data set directly relating fuel quality, its price, and utilities' purchases. These data are then used to estimate the functional relationship among those variables.

The major difference between the two approaches is thus the data set on which they are based: actual price/quantity observations in the hedonic price framework (Chapter V); and hypothetical price/quantity/attributes observations in the direct survey approach (this chapter). The relative strengths and weaknesses of the two methods stem from that difference. On the one hand, because it is based on actual rather than intended actions, the hedonic price model may provide more accurate information. On the other hand the range of attributes and hence fuels that can be investigated with hedonic methods is narrower. Indeed, as it is based on actual data, an hedonic study is limited to the fuel charac-

teristics for which such data exists and its predictions are valid for that range of fuels. With a survey instrument, on the contrary, one can create and therefore investigate entirely new fuels.

The procedures and design criteria adopted in the survey used to elicit the fuel quality preferences were based on a branch of the economic literature usually known as "Contingent Valuation" (CV). So, in the next section, before describing the survey instrument, we briefly review the CV literature to highlight the most crucial issues involved in the design of sound questionnaires. Section C deals with the econometric analysis of the survey answers. The specification of an econometric model relating purchases, prices and fuel attributes is discussed and estimates of the partial elasticity of purchases with respect to fuel prices and attributes are produced. Section D presents the main conclusions of the econometric analysis and provides some tentative explanations of the results. Finally, in appendices to the report, we present the raw survey data, some summary statistics of that data and a copy of the survey instrument used.

B. REVIEW OF CONTINGENT VALUATION LITERATURE AND ITS IMPLICATIONS FOR THE DESIGN OF A "MARKET SURVEY FOR REDUCED SULFUR COAL"

1. Overview of the main issues raised in the CV literature

The Contingent Valuation (CV) approach to benefit estimation, also referred to as the direct survey approach, asks individuals their dollar valuation of a commodity, usually a good or service not traded in an actual market. Typically, by a survey instrument, an hypothetical market is set up and price responses are elicited. As Randall et al. (1983)

put it, "CV devices involve asking individuals, in survey or experimental settings, to reveal their personal valuations of increments (or decrements) in unpriced goods by using contingent markets ... Contingent markets are highly structured to confront respondents with a well defined situation and to elicit a circumstantial choice contingent upon the occurrence of the posited situation."

Thus, CV deals with hypothetical situations. The crucial assumption of this methodology is that individuals' expressed preferences are consistent with what their behavior would be if they were involved in a real decision. Smith and Desvousges (1986) consider that "the hypothetical character of CV is both its strength and its greatest weakness. Because it can be based on hypothetical commodities and circumstances, CV offers a wide range of possibilities for addressing different problems. Yet, this exposes CV to the pitfalls associated with describing the hypothetical situation ... in sufficient detail to make it believable for respondents."

The hypothetical nature of CV surveys indicates the need for considerable attention in the instrument design phase to provide a credible survey questionnaire. The respondent must be able to perceive the experiment as a realistic approach to measuring the commodity under consideration. Randall (1974) lists some desirable characteristics of the survey instrument:

- Test items must have properties similar to those in the actual situation.
- Situations posited must be concrete rather than symbolic or too abstract.

- The test items should involve institutionalized or routinized behavior, where the role of expectations of respondents is well defined.

That is, if a CV survey is to provide a "substitute" for a market, it must be designed in such a way that respondents may place themselves and the good in question in a market-like context. Indeed, evidence quoted in Cummings et al. (1984) indicates that where the good is ill-defined or the hypothetical situation is not understandable, the CV bids tend to be unstable in the sense that subtle changes in the survey specification (such as the introduction of other goods or budget constraint like trade-offs) result in substantial changes in average bids. Thayer (1981) considers the existence of significant biases in CV (i.e., poor performance of CV surveys in eliciting what the actual behavior would be) as a survey design error. As long as the survey follows closely the requirements mentioned above, Thayer reckons that the bias should not to be significant.

These general remarks, in spite of their very general nature, convey important information for the design of the "Market Survey for Reduced Sulfur Coal." As reduced sulfur products currently being tested are not completely similar to the fuels currently used, and the decision to buy such a fuel involves considerable uncertainty and thus cannot be considered routine, an iterative survey procedure should have been adopted, since it allows for learning. Unfortunately, due to time limitations, we ran the survey only once. Running several survey rounds would have enabled respondents to become familiar with the product and with the kind of reasoning the survey demands. Moreover, an iterative format might have given the game more "credibility" as it would enable "market" infor-

mation (i.e., some indicators of the global answer pattern) to be fed back, in each round, to the respondents. Thus the respondent would not only know that the "game is being played" but also that the "market" was taking the product seriously.

The need for learning also requires a "constructive" question design in the sense of one that leads the respondent gradually into the kind of reasoning and stance desired.

In most (if not all) CV surveys, a quantity of the commodity under analysis is presented and the respondent is asked to bid on the quantity; i.e., to state the maximum price he is willing to pay for the given quantity. This is so because most surveys deal with "public goods" -- goods that are provided in the same amount to all individuals concerned.

Clearly coal and solid fuel alternatives are not public goods. The typical market experience of utilities is to determine what amount to buy and consume at a given price. Thus, if the survey bidding is to replicate the real bidding process (as it should), it must collect "quantity bids" instead of "price bids." The survey must ask the question of how much are utilities willing to buy at hypothetical prices and not how much are they willing to pay for desulfurized coal (see, question 7 of the survey instrument in Appendix A). Yet, the main output of this survey--an estimated demand curve for a reduced sulfur coal product -- will permit insight into the latter question too, because once the demand curve is "known," the two questions are exactly the same. Thus, the reason for asking the "willingness to buy" at a given price and not the "willingness to pay" (WTP) for a given quantity is just that the former

question is probably more familiar to the utilities' officers in charge of coal purchases than the latter.

Traditionally the literature is organized around the discussion of potential biases in using CV to measure the values of goods. This focus on biases is justified, since it is only by understanding the critical issues that one can conceive sound questionnaires enabling meaningful inference.

There are several ways in which potential biases can be classified. The conventional taxonomy distinguishes between "general biases" -- How does strategic consideration of the respondent affect their answers? Does the information provided matter? How good a guide to actual behavior are responses to hypothetical situations -- and "instrument related biases" -- Is it necessary to iterate initial bids? In formats where the interviewer chooses the initial bid, does this starting point affect the outcome of the bidding process? Is the payment vehicle important?

This classification certainly highlights the sources of potential problems with CV methods. However, it is not pedagogic in the sense that it does not relate directly to the questionnaire design (which is, after all, the main practical problem faced in any CV research). Smith and Desvousges (1986) consider that "[there is] sufficient evidence to conclude that many of the conventional biases, if they exist at all, can be viewed as problems in either the framing of the contingent commodity or in the survey procedures."

Smith and Desvouges (1986) provide an alternative taxonomy which addresses much more directly the practical issues involved in eliciting re-

spondents preferences by a direct survey approach. They distinguish between "Framing Biases" and "Procedural Biases." Framing includes "the physical setting in which the interview takes place and the mental setting that is created by the survey questionnaire [Smith and Desvouges called these two settings the context], the specification of the commodity, and the format of the questions used to elicit an individual's response." Survey procedures include "the process involved in collecting data. They can range from selecting a representative sample to the training of interviewers." Most of the issues that may give rise to "procedural biases" are not particularly relevant to the survey in question since it was a mail survey. The survey sample was essentially equal to the population of utilities that purchased Illinois coal in 1986. Hence, the following discussion addresses only the framing biases which are relevant to a survey instrument concerning coal purchasing.

a. Context. The CV, as all direct methods of preference revelation is subject to the strategic behavior or free-rider critique. Depending on how respondents perceive the consequences of the hypothetical experiment, they may behave strategically, misrepresenting their true preferences. Based on previous studies, Cummings et al. (1984) and Thayer (1981) argue that strategic behavior can be neutralized by sound questionnaire design and it is therefore seldom encountered in survey studies. Furthermore, they argue, experimental evidence has indicated that strategic biases may be of little consequence. Nevertheless, Rowe et al. (1980) found that provision of information concerning the overall mean bid gave rise to the classical free-rider problem (regression of the bids

towards the mean). This indicates that strategic bias is a real issue which must be guarded against in survey design.

For our "Market Survey for Reduced-Sulfur Coal" a strategic behavior problem is to be expected. Prospective buyers, who put no money on the line to back up their answers and who anticipate that their bids may encourage the launching in the market place of reduced sulfur products, have incentives to overstate quantities in order to add these products to their choice set even if they have no intention of buying them. There isn't much that can be done to overcome this problem, besides being aware of its existence and exercise caution where interpreting the survey results.

b. Commodity specification. If the bids are to be meaningful, respondents must know exactly what they are bidding for. Not only must the description of the commodity be complete but it must also consider the procedures used by individuals to form perceptions and their ability to process the information provided. That is, the characterization must be "understandable," and must convey information analogous to that available in real situations. According to Cummings et al. (1984), one of the basic issues that affects the accuracy of CV is whether the information provided appropriately focuses the "mental picture" formed by respondents. They suggest several aspects of perceptions that can affect the accuracy of CV: "All subjects are evaluating the same commodity; perceptions are invariant over time; and perceptions are independent of the quantity and quality of information provided." They conclude that, for accuracy, CV must reflect preferences rather than perceptions. Other authors, however, dispute the conclusion. Smith and Desvouges (1986),

for instance, consider that for every commodity (contingent or not) individual perceptions are inseparable from preferences and are important elements in determining the WTP. What seems however undisputed in the literature is that contingent commodities must be specified in a way that is both understandable and familiar to the respondent.

The main implication of these considerations as to our survey is that the proposed fuels must be characterized as completely as possible. The information provided must be sufficient to enable utility officers to make intelligent decisions. That is, when bidding they must be cognizant of all the implications for unit performance from using the fuels. Furthermore, the characterization of the alternative fuel should be provided in a format which is familiar to the respondent, i.e., similar to standard utility coal procurement specifications.

The regulatory environment is also an integral part of the contingent commodity under analysis. Clearly the attractiveness of reduced sulfur fuels depends on the regulatory setting utilities expect will prevail. Thus, in the survey the regulatory scenario must be clearly specified. (See pp. 5,6 of the survey instrument in Appendix A.)

c. Question format. The format of the question used to elicit values is a crucial link in the framing of the contingent commodity. An "ideal" format would be understandable to the respondent, simple and convenient to use in a questionnaire and it would not artificially influence the magnitude of the bids.

Researchers have developed several different ways to ask the valuation questions. Among the most widely used question formats are:

- "Direct Question":The respondent is directly asked his willingness to pay (WTP) for a stated change in the amount provided of the good.

- "Bidding Game":Answers are elicited in turns of "yes" or "no" to questions expressed in the form "would you pay $x for the commodity?" Based on whether there is a "yes" or "no" answer, the amount is raised or lowered. The amount which elicits the highest "yes" response is considered respondent's WTP.

- "Payment Card": Under this approach respondents are not directly asked their WTP. Instead the elicitation proceeds as follows: (1st) a change in the commodity under evaluation is specified; (2nd) A card with an array of potential WTP values is provided to the respondents; (3rd) Individuals are asked to select the value that better represents their WTP.

- "Take it or leave it": The respondent is asked whether or not he is willing to pay a given amount for the contingent commodity. Only a "yes" or "no" answer is required. The responses are then used in estimating a "discrete response model."

- "Ranked Choice": The respondent is faced with different hypothetical market outcomes to be ranked. These ranks are then used to estimate individuals WTP by "discrete choice" type of methods.

Whatever format is adopted the key features that influence its overall effectiveness are the ease of understanding and the ease of avoiding influences on the valuation responses. The former indicates how easy it is for people to understand the questions being asked and to process the information the question implies. Brookshire et al. (1981) point out the existence of evidence suggesting that it is better to ask a question requiring "yes" or "no" answers rather then questions requiring implicit calculations. It seems also that an ordinal information processing task, like the one required for the "Ranked Choice" or "Take it or leave it," is easier to perform then the cardinal task implied by "Direct Question."

The second key feature refers to the possibility that the respondents may "anchor" on some artificial reference point in the question format. Two main potential "anchors" are usually discussed in the literature: the starting point of a bidding game and the payment vehicle. The question is whether the starting point may suggest a bid to the respondent and thus affect the outcome of the game or whether the payment vehicle may itself imply some reference for the value of the commodity under analysis (e.g., when one is asked to make a hypothetical payment in the form of a utility bill, what may come to mind is one's typical monthly bill). Existing data is inconclusive as to the impact of the starting point. Cummings et al. (1984) were unable to establish any definite problem arising from the payment vehicle, although, they were unwilling to dismiss it as a potential problem in CV.

The Cummings et al. (1984) state-of-the-art survey leave us the following assessment of CV potential: CV will be most accurate where least needed and least accurate where most needed. That is, CV can accurately measure values of commodities that individuals can easily understand and relate to a market based experience. For unfamiliar commodities, involving substantial uncertainties the method will be less accurate.

2. Implications for Design of the "Market Survey for Reduced-Sulfur Coal"

In the previous section some general implications of the CV literature for the design of the survey instrument actually used were already mentioned. To summarize, those major lessons were:

- Utilities should be asked for "quantity bids" rather than for "price bids";

- The offered clean fuels should be characterized as thoroughly as possible, in a way which is familiar to respondents.

Below we address the issues raised by the implementation of these broad guidelines and present the main ideas underlying the design of the survey.

a. Format. Which of the questionnaire formats mentioned in Section 1 should be adopted for the "Market Survey for Reduced Sulfur Coal"? The choice must consider the following:

- The survey design has to be compatible with the quantity and quality of the information one has available so that the "right" questions may be asked. For instance, formats that require some knowledge of market outcomes should be dismissed since no supply side information is available.
- The chosen format must fit well into a "willingness to buy" framework.
- The choice format must be simple and easy to use.

Formats like "Take it or leave it" (in our context: "Is the utility willing to buy the amount x at price y? Yes or No?"), "Bidding game" or "Ranked Choice" are inappropriate: the first two because they require prior information about the demand curve for reduced-sulfur fuels so that a sensible question might be asked; the last one because it requires information on market outcomes.

So we are left with two candidates: "Direct Question" or "Payment Card." The latter is preferable since it appears to be easier for the respondent in that it provides him an array of alternatives to choose from.

The "Payment Card" format, in a survey designed to elicit respondent "willingness to buy" (not WTP), starts by specifying a "price change"

(here a price differential with respect to the price of currently used fuel) and then asks the respondent to choose, out of an array of different amounts, the one that best describes his buying intention. (See question 7 of the survey instrument in Appendix A.)

b. Product characterization. The specification of the fuels being offered accounts for pages 5 and 6 of the survey. This specification obeyed two major concerns: a) if the study was to provide useful information about how utilities value coal's sulfur content and volatility, a "significant" number of fuels with different contributions of these attributes had to be offered; b) at the very least, any useful specification had to include the proximate and ultimate analysis of the fuels. As it was clearly unfeasible to get a sufficient number of "real" clean fuels, the strategy adopted was to take as references the laboratory analyses of two such fuels (one char and one froth-flotation product) and then to generate the remaining by perturbing some of the parameters in those analyses, staying within the range of quality levels indicated by the laboratory analyses as well as expert advice received from Illinois Geological Survey personnel. Specifically, three sulfur content levels (0.45%, 0.95% and 1.78%), three volatility levels (15.12%, 25.14% and 35.26%), and two ash fusion temperatures were considered. Two different raw ash contents were specified as well. These were not considered treatments; i.e. were not randomly apportioned to the sample. Indeed they were systematically assigned to low and high ash fusion temperature specifications and their inclusion (rather than a single ash level) was an editing oversight.

Using two "trees" of volatility and sulfur combinations, one for each ash fusion level, eighteen different products were generated. The ash fusion temperatures distinguish between two fundamentally different boiler types. "Wet-bottom" furnaces melt the ash, which requires a low ash fusion temperature (2400°F and below). "Dry-bottom" furnaces keep ash in a solid state, for which a higher fusion temperature is needed. The sample was divided into groups, "wet bottom" and "dry bottom" generating units; then the products with high ash fusion temperature were randomly allocated to dry bottom plants and those with low fusion temperature to wet bottom plants.

Other important attributes were set constant over the sample: moisture content (6.57% AR), chlorine content (0.10% MF), equilibrium moisture (4.5%) and Hardgrove Grindability Index (48 at 4.5% moisture). Finally, using the data in the proximate analysis and a "Dulong-type equation" the Btu/lb levels were calculated. The generated analyses are summarized in Tables B-I and B-II and reproduced in their entirety in Appendix C.

Besides the proximate and ultimate analysis (p. 5 of the survey) further information was provided (see p. 6). It refers to handling characteristics and delivery conditions of the product. Its main goal is to make the offered fuel as credible an alternative as possible.

c. Initial price. The formulation of a "payment card" type of question to elicit the "quantity bid" (p. 7 of the survey) faced two major problems: the determination of a "reasonable" price for the fuel being offered -- i.e., a price at which the question "how much are you willing to buy" could be asked--and the set-up of a relevant quantities

choice set -- i.e., what would be the appropriate scale of an array of quantity responses. The solution found for the latter problem was to ask utilities to choose the percentage of their 1986 coal usage that they would be willing to replace with the offered product.

Concerning the starting price question, two major issues were involved: 1) the prices should reflect the qualities of the fuels, namely its sulfur content and volatility; but, 2) some provision had to be made to avoid the zero purchases that would be induced by stating too high a price. Furthermore, since the valuation of sulfur and volatility is likely to differ from utility to utility, the offer prices had to be "personalized", i.e., set in a way to reflect each utility's likely valuation. The concern with avoiding zero quantity answers due to excessively high prices can be justified on two grounds: 1) the smaller the dispersion of the answers the less reliable statistical inferences are; and 2) because those answers would make it difficult to identify a "reservation price" or, in other words, to locate the position of the demand curve for fuel in the price-quantity space.

The utility specific prices were generated in four steps: 1) using time-series data from 1986 on utility $\underline{i}$ purchases (from FERC form 423 and reported in page 3 of the survey), partial elasticities of the price paid with respect to the sulfur content and Btu (as a proxy for volatility) were computed (for convenience we denote them by e_{Si} and e_{bi} respectively); 2) using these same time-series, averages of the price, sulfur and Btu were calculated ($\bar{p}_i$, $\bar{s}_i$, $\bar{b}_i$); 3) with this information and the knowledge of the sulfur content and Btu of the fuel being offered to utility i (s_i, b_i), an estimate of the premium or discount (relatively to

$\bar{p}_i$) at which the clean fuel was to be offered was constructed using the following relationship

$$\frac{p_i}{\bar{p}_i} = 1+e_{si}\frac{\bar{s}_i - s_i}{\bar{s}_i} + e_{bi}\frac{\bar{b}_i - b_i}{\bar{b}_i}, \qquad (1)$$

yielding the percentage in question 7 of the survey; 4) this premium or discount multiplied by a quantity weighted average of past prices (the reference price on page 3) gave the offer price of the fuel.

This procedure requires two comments. Btu was used as a proxy for volatility because there was no secondary information on the volatility of utility coal purchases. Indeed one of the purposes of the survey is to obtain that information (cf. question 6). The price computed above was only intended to be a rough starting point for a "bidding game" which should be improved upon in subsequent rounds, using the volatility information in question 6 as well as the information provided by the purchases. An iterative format would then add this operational advantage to those mentioned in the first section and concerning "learning" and "credibility" effects. Unfortunately due to time constraints it was not possible to launch a second round. Another provision to avoid "starting point" induced biases -- namely these caused by excessively high prices-- was incorporated: utilities that didn't want to buy any fuel at the stated price are asked to indicate at which price they would purchase 5% of their current burn (question 8 of the survey).

As was mentioned earlier in this chapter, the inquirees' expectations and perceptions are a decisive determinant of their answers. However, they are very difficult to control for; i.e., it is difficult,

if not impossible, to find survey design variables which reflect the multitude of factors that may affect each answer. The ninth question in the survey was included in an effort to elicit some of these hidden factors. Specifically, it tries to elicit information on how the respondent's perceptions of the fuel impact his bids and to single out the main determinants of those bids.

3. Potential limitations of the survey approach

CV appears to be a useful tool to assess the market potential for reduced-sulfur Illinois coal. As the overview of the literature and some common sense indicate two main factors condition the reliability of the preferences revealed by the survey:

- Did utilities perceive the clean fuels they were offered as credible and usable alternatives? Clearly there is no definitive answer to this question. But it seems equally clear that a crucial aspect is the information on the fuel characteristics that was provided. This information was probably as accurate and thorough as possible given the fact that most of the products offered do not really exist. Nonetheless it may have been insufficient for informed decisions to be made. Indeed, comments by some utility officers indicate that at least results of test burns would also be needed.

- A survey only elicits intended actions. These may be different from what actual actions would be. The main reason is that in the hypothetical setup of a survey, agents do not bear the costs of their stated actions and therefore have smaller incentives to be accurate.

These considerations lead to the conclusion that the answers to the survey should be interpreted with caution and that the information regarding the valuation of coal attributes obtained using the survey data should be complemented by and cross-checked with results of studies based on actual purchases.

C. ECONOMETRIC ANALYSIS OF THE SURVEY RESPONSES

1. Model Specification

The purpose of an econometric analysis of the survey answers is to determine if and how the proportion of the current burn utilities are willing to buy (Q) is related to the survey design variables (X), namely to the attributes and price of the fuels being offered.

A casual inspection of the "quantity answers" (questions 7 and 8) reveals that part of them (about 50%) are zero, i.e., about half of the plants in the sample were not willing to buy the fuel they were offered at any (nonnegative) price.

In this situation, linear regression techniques are inappropriate since the existence of a limited dependent variable (i.e., the fact that Q has to be nonnegative) makes the model intrinsically nonlinear. The appropriate model is the following ("Censored Regression" or "Tobit Model"),

$$q_i = \beta' X_i + u_i \quad \text{if RHS} > 0 \qquad (6\text{-}1a)$$

$$q_i = 0 \quad \text{otherwise} \qquad (6\text{-}1b)$$

where u_i is a $N(0,\sigma^2)$ random variable. The idea behind this model is that, when utilities decide to buy the fuel, the amount purchased is assumed to be linearly related to the covariates X. However this linear relationship cannot hold for all the observations. Indeed, if it could, given the disturbance term, it would be possible to get positive as well as negative deviations from the limiting value 0. Since this is not the case, the range of the dependent variable has to be truncated at 0.

Using this model we will be mainly interested in the estimation of the marginal effects of the regressors on the expected value of the proportion of the current burn utilities will buy (the "expected purchase", for short) - expected value over nonnegative answers (E(Q)) as well as over positive answers only (E(Q|Q>0)).[15]

The set of potential explanatory variables (X) includes the "Reference Coal" characteristics (Reference Ash (RA) and Reference Sulfur (RS)), the treatment variables (Sulfur (S), Volatility (V) and Ash (A) content of the offered fuel), price variables (average price of current burn (RP) and offer price of the alternate fuel (P)) and technological variables such as the existence of cold side electrostatic precipitators (ESP = 1 if the plant has these precipitators, 0 otherwise) and a variable reflecting whether the plant is dry or wet bottom (T = 1 if "dry", 0 otherwise).

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[15]The expected value of the endogenous variable Q and its partial derivatives with respect to the exogenous variable x_j are given by (c.f. Maddala, 1983, pp. 158-160):

$$E(Q) = \Phi(Z)\,\beta'x + \sigma\phi(Z)$$
$$E(Q|Q>0) = \beta'x + \sigma\,\frac{\phi(Z)}{(\Phi(Z))}$$

$$\frac{\partial}{\partial x_j} E(Q) = \Phi(Z).\beta_j$$

$$\frac{\partial}{\partial x_j} E(Q|Q>0) = \left(1 - Z\,\frac{\phi(Z)}{\Phi(Z)} - \left(\frac{\phi(Z)}{\Phi(Z)}\right)^2\right)\beta_j ,$$

where σ is the standard error of estimate, $Z = \beta'x|\sigma$, Φ is the normal c.d.f. and ϕ the normal p.d.f.

Pretesting has indicated poor explanatory performance of the reference attributes (RA, RS) and of the dummy ESP. The way the survey was designed precludes the simultaneous use of the Ash treatment (A) and of the dummy variable T (e.g., see the raw data table). The potential regressors are therefore, P, RP, S, V and T.

Having chosen the covariates, one must specify a functional form; i.e., determine the form those variables enter the regression equation (the demand function for the clean fuels). Ideally this function should be specified in such a way that there exists a (well behaved) technology from which that demand function could be derived. In our case following rigorously this requirement proved to be difficult because utilities' demand for coal is a demand for a given set of attributes whose price is not observed. We have thus followed a looser approach to the specification of the demand equation. This was set to meet a number of requirements which were felt to be desirable, namely: (i) the main characteristics of the fuels being offered, sulfur and volatility content, should be present not only because they are the object of the study but also to reflect the heterogeneity of fuels; (ii) the reference price (RP) and the offer price (P) should enter has a ratio (RP/P) to capture the idea that only relative prices matter, that is, demand should not change if, ceteris paribus, RP and P change in the same proportion; (iii) the variables should enter in a nonlinear form so that their impact on purchases depends on the level of those variables; (iv) engineering considerations suggest that the behavior of wet and dry bottom plants differ, so the influence of the dummy variable T should be measured.

The specification of the nonlinear effects mentioned in (iii) was suggested by the form variables enter a demand function derived from a generalized Leontief (GL) cost function (Diewert, 1974). Demand functions derived from a GL cost function are linear in $\sum_i x_i^{1/2}$ where x_i is the price of input i relative to the price of the input whose demand is being analyzed (Varian, 1984, p. 180). As utilities' implicit valuation of sulfur and volatility is not observed, it was assumed (after some testing) they were related, in the relevant range, to sulfur and volatility contents by $k_1 S^{-1}$ and $k_2 V^{1/2}$ respectively (where k_1 and k_2 are constants).

Several specifications of the regression equation were tested. The following represents, we feel, the best compromise between theoretical soundness and goodness of fit:

$$q^* = \beta_o + \beta_1 \left(\frac{RP}{P}\right)^{1/2} + \beta_2 \frac{RP}{P} + \beta_3 V^{1/4} + \beta_4 S^{-1/2} + \beta_5 T + \beta_6 T \cdot S^{-1/2} \quad (6\text{-}2a)$$

Before presenting the regression results one should mention that <u>the hypothesis that the behavior of wet and dry bottom plants differs, was clearly rejected</u> in this sample. Indeed the likelihood ratio test statistic (LR) for the hypothesis $\beta_5 = \beta_6 = 0$ is LR=0.24, clearly inside the acceptance region of a chi-square (χ^2) distribution. This result has proved to be robust to the form the sulfur dummy is introduced in the regression equation. Therefore, in the regressions below T and $S^{-1/2} \cdot T$ were omitted. We call this

$$q^* = \beta_o + \beta_1 \left(\frac{RP}{P}\right)^{1/2} + \beta_2 \frac{RP}{P} + \beta_3 V^{1/4} + \beta_4 S^{-1/2} \quad (6\text{-}2b)$$

2. Estimation

All the models were estimated by Maximum Likelihood, using the computer package Shazam 5.0 (White, 1978). The data is described in Appendix B (Table I). The maximum likelihood estimation of the Tobit model (6-1) which has (6-2) as systematic part, yields the estimates in Table 6-I.

Two tests come immediately to mind: "No price effects" and "No treatment effects." The hypothesis that the treatment variables (S, V) don't exert a significant influence on the purchases, at any level of S and V whatsoever, is rejected at 5% significance level. Indeed the likelihood ratio test statistic for the null $\beta_3=\beta_4=0$ is LR=7.42. The hypothesis of no price effects at any level of the exogenous variables ($\beta_1=\beta_2=0$) was clearly rejected (LR=16.6). The hypothesis of a perverse price effect at the mean value of the exogenous variables, i.e., $\partial EQ/\partial P \geq 0$ (at the means) is also clearly rejected (the asymptotically normal test statistic assumes the value - 2.12, which is inside a one-tailed 5% normal rejection region).

The estimate of the coefficient of $S^{-1/2}$ has a "perverse" sign in that it implies that purchases will increase when sulfur content increases. However the simple hypothesis that the sulfur influence is zero ($\beta_4=0$) cannot be rejected even at a 10% significance level when correction for finite sample is made (the 10% critical level with a correction for the finite sample is about 3 while LR=2.72).

The estimated partial derivatives and elasticities of the average quantity response with respect to the price and volatility content of the offered fuel are presented in Table 6-II.

These results clearly indicate that, for a given quantity bought, utilities are willing to pay more for higher volatile content. A rough estimate is that if the volatility were 10% higher than the average (27.5% instead of 25.01%) utilities would be willing to pay about 141¢-/MMBtu instead of 132.7¢ (keeping the expected purchase quantity and reference price constant at their average levels, 6.56% and 163.47c/MMBtu respectively).

The results in this section indicate that the sulfur content did not influence the quantity answers in a statistically significant way. The data appears to indicate that the dropping out of sulfur effect is not due to different and offsetting tastes for sulfur of wet and dry bottom plants. Indeed, as we have seen, the inclusion of T and $S^{-1/2} \cdot T$ is rejected. Furthermore, in initial testing, models which include $S^{-1/2} \cdot T$ instead of $S^{-1/2}$ or both $S^{-1/2} \cdot T$ and $S^{-1/2}$ were clearly rejected in favor of the specification adopted in this section. Some possible explanations of this result will be presented in Section D.

Now we will explore other channels through which sulfur may have influenced purchase intentions. Specifically we will test if utilities are just concerned with meeting their SIP's, rather than with the actual value of the sulfur content (which was already seen to exert a negligeable influence). The inclusion of the dummy variable SD (SD=1 if $S \leq RS$, 0 otherwise) tries to capture this effect.

The model becomes,

$$q^* = \beta_0 + \beta_1 \left(\frac{RP}{P}\right)^{1/2} + \beta_2 \frac{RP}{P} + \beta_3 V^{1/4} + \beta_4 SD + \beta_5 \left(\frac{RP}{P}\right)^{1/2} \cdot SD \qquad (6\text{-}3)$$

The maximum likelihood estimation of (6-1) taking (6-3) as the specification of the systematic part, yields the estimates in Table 6-III.

Having this model as a basis, several nested hypothesis can be tested, namely hypothesis on the joint and separate influence of the "attributes" V and SD. Before reporting these tests it is worth noting that the hypothesis that "prices do not matter" whatever RP and P may be (β_1=β_2=β3=0) is clearly rejected (LR=21.6). The hypothesis that the volatility treatment has no effect on expected purchases is also rejected at the 10% significance level even after correction for finite sample (LR=3.64). Several tests of the influence of SD can be performed: no direct influence, no influence through the price effect and no influence through either channel. The first two are clearly rejected (LR about 5 in both cases) at the 5% level. The joint hypothesis (β_4=β_5=0) can only be rejected at the 10% level (LR=5.4), but this rejection also holds after correction for finite sample. Finally the hypothesis that "only prices are important" no matter what the treatments may be (β_3=β_4=β_5=0) is clearly rejected (LR=10.12).

With this model it is possible to study how the sulfur level, relative to the "reference sulfur", affects the price and volatility elasticities and the expected purchases. The price elasticity of the expected purchases and its derivative with expect to volatility are presented in Table 6-IV.

The price elasticities when SD=0 have perverse signs; i.e., they are positive. However, at the mean reference price (163.47c/Mbtu) and at the mean offer price (132.70c/Mbtu), the hypothesis that the offer price of the fuel exerts no influence when SD=0 is clearly not rejected. Indeed,

the test statistic for a linear hypothesis equivalent to the nonlinear hypothesis $\partial E(Q)/\partial P=0$ has the value .25, which is well inside the acceptance region of a normal distribution. Moreover this rejection also holds for values of RP/P in the "reasonable" range, [1/2,2]; i.e., for offer prices between 82¢/MMBtu and 327¢/MMBtu (given RP=163.47¢/MMBtu).

On the other hand, when SD=1, the price derivatives have the right signs and are significantly different from zero (the asymptotically normal test statistic takes the value 2.99).

One way of comparing both the "slope effects" and "level effects" of the dummy variable SD is to compare $E(Q|SD=0)$ with $E(Q|SD=1)$. When SD=0 the expected purchase (at the mean values of the exogenous variables) is 20.7% whereas when SD=1 it is 14.8%. However, the hypothesis that the two expected values are equal cannot be rejected. Indeed, the Wald test statistic takes the value 1.91 which is inside the 5% nonrejection region of a chi-square distribution.

Summing-up, Model 6-3 indicates that, when the offered fuel does not comply (on average) with the SIP's (SD=0), utilities purchase intentions depended mainly on the volatility content of the fuel. For an offered compliance fuel, both price and volatility were important determinants of intended purchases. The model also shows that the amount a "typical" utility was willing to purchase of a fuel with the sample average characteristics and price was not significantly affected by that fuel having a sulfur content higher or lower than the sulfur content of the coal currently used.

A MARKETING SURVEY AND ASSESSMENT OF THE POTENTIAL FOR DESULFURIZED ILLINOIS COAL

by

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August 31, 1987

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D. CONCLUSIONS

The econometric analysis of the survey data seems to indicate four main conclusions

- Wet and dry bottom plants stated buying intentions that were not significantly different.
- The intended purchases are sensitive to the prices of the reduced-sulfur fuels.
- Utilities have a taste for higher volatility.
- Utilities did not reveal a taste for low sulfur, in the sense that their buying intentions were not significantly affected by the sulfur content of the offered clean fuels.

This last conclusion should be regarded with some suspicion not only because it seems to be counterintuitive but also because it contradicts hedonic studies which show that utilities' actual purchases reflected a willingness to pay a premium for low sulfur coal (Chapter 5). One possible explanation stems from the difference between actual and intended actions, the latter being those evaluated in a survey. These differences may have at least two origins. As utilities do not bear any cost for their stated buying intentions, the incentives for accuracy are thereby reduced. On the other hand in a survey set up it is very difficult to control the expectations and perceptions of the respondents. Thus, although the analyst thinks that respondents are reacting only to the design variables, their answers may in fact be conditioned by a multitude of factors external or internal to the survey, for which no control was exercised (i.e., factors to which does not correspond any design variable). For instance, in the hypothetical setting of the survey, the regulatory constraints on emissions may not be perceived to be as

decisive as they are in the "real world." Also, it may be the case that the information provided about the offered fuel was insufficient for a knowledgeable decision to be made.

A different set of possible explanations emphasizes more "objective" causes. First, there are technical problems associated with the burning of low sulfur coal in facilities with electrostatic precipitators, which account for 73% of the plants in the sample. Second, it is conceivable that utilities do not have an "intrinsic" taste for low sulfur coal, i.e., in a unregulated environment they would not be willing to pay a premium for cleaner coal. So, if compliance with the emission standards is already ensured by the current burn and if the new fuel is to be blended with the coal currently used, the buying intentions may not reflect any strong dependence on the sulfur content of the offered fuel.

Table 6-I: Estimates from Equation (6-2b)

	$(RP/P)^{1/2}$	(RP/P)	$V^{1/4}$	$S^{-1/2}$	CONST
Coefficients[16]	14.523	-5.254	1.863	-0.812	12.735
T-ratio	2.354	-2.207	2.296	-1.650	-2.950

Log of Likelihood = -161.16

Standard Error of the Estimate = 29.26

[16]These are estimates of the standardized coefficients, i.e., of the ß's in (B) divided by the standard error (σ) of the disturbance term, u, (c.f. Model (A)). Estimates of the ß's can be obtained multiplying the standardized coefficients by the standard error of the estimate. We report the standardized coefficients because the computer package used for estimation only produces estimates of the covariance matrix of the standardized coefficients estimators. Therefore, all the inferences presented in this chapter had to be based on the standardized rather than on the original coefficients.

Table 6-II: Elasticities and Derivatives of the Average Desired Quantity (Model (6-2b))(*)

		Price	Volatility
E(Q)	Derivative(**)	-.208	5.875
	Elasticity(***)	-4.213	
E(Q|Q>0)	Derivative	-.147	4.157
	Elasticity	-1.691	

(*) Evaluated at the mean value of the variables involved.

(**) $\partial E(Q)/\partial x$ and $\partial E(Q|Q>0)|\partial x$, with x = Price, Volatility.

(***) $\partial \ln E(Q)|\partial \ln x$ and $\partial \ln E(Q|Q>0)|\partial \ln x$, with x = Price, Volatility.

Table 6-III: Estimates from Equation (6-3)

	$(RP/P)^{1/2}$	(RP/P)	$V^{1/4}$	SD	$(RP/P)^{1/2}$.SD	CONST
Coefficients(*)	15.758	-7.341	1.571	-5.936	5.060	-11.440
T-ratio	1.953	-2.194	1.900	-2.136	2.060	-2.146

Log of Likelihood = -159.81

Standard Error of the Estimate = 29.027

(*) Estimates of the standardized coefficients (c.f., footnote 1 on Table 6-I)

Table 6-IV: Elasticities and Derivatives of the Average Desired Quantity (Model (6-3))(*)

		Price		Volatility	
		SD=0	SD=1	SD=0	SD=1
E(Q)	Derivative(**)	.0458	-.318	.454	.376
	Elasticity(***)	.294	-2.855		
E(Q|Q>0)	Derivative(**)	.0322	-.225	.319	.265
	Elasticity(***)	.144	-1.172		

(*) Evaluated at the mean values of the variables involved.

(**) $\partial[E(Q)|SD=i]/\partial x$ and $\partial[E(Q|Q>0)|SD = i]|\partial x$ with i=0, 1 and x = Price, Volatility.

(***) $\partial \ln [E(Q)|SD=i]/\partial \ln x$ and $\partial \ln[E(Q|Q>0)|SD=i]/\partial \ln x$ with i=0, 1 and x=Price, Volatility.

CHAPTER VII. CONCLUSIONS AND RESEARCH IMPLICATIONS

A. CONCLUSIONS

The market position of Illinois coal has been seriously eroded over the past two decades, largely because of regulations concerning sulfur content. In order to recapture the market, means of reducing sulfur levels in Illinois coal must be found. A variety of processes that can achieve the needed reductions are being investigated. It appears that any such process will be costly, and it is not clear that the returns will outweigh the costs. The returns would be in the form of a higher value in the market place for reduced sulfur coals (actually, a reduction in the price penalty caused by high sulfur levels). This research set out to determine whether and to what extent reducing sulfur levels would increase the value of Illinois coal in the market place.

Among the coal attributes changed by the technologies of interest here are sulfur levels and volatility. (Of course, different technologies change different attributes. All reduce sulfur, but some have little or no impact on volatility.) These two attributes were singled out for analysis in this study in part because of their significance to the CRSC research program. The research focused on the coal demand of the largest single coal using sector, the electric utility industry.

The results of the analyses are generally consistent with expectations. Using hedonic techniques on data for actual market transactions by Illinois utilities, reducing sulfur content was shown to be worth from about $0.70 to $1.00 per million Btu for each pound of sulfur per million Btu of heat content. On a per ton basis, assuming 12,000 Btu/ton, this

works out to $17 to $24 per ton. The actual value varies across individual consumers and with other attributes of the coal, such as ash and heat content. There is a great deal of statistical uncertainty associated with this low-sulfur premium, uncertainty which we are currently seeking to reduce. Furthermore, these results only apply to Illinois consumers.

Due to the absence of actual market data that specifies volatility levels, a survey was used to elicit the value of volatility (and sulfur) among current purchasers of Illinois coal. Preliminary analyses of the survey responses clearly indicate that utilities are willing to pay more for higher volatile content. Given coal with 25% volatile matter, an increase of 10% (to 27.5%) would warrant a price premium of about 8¢/MMBtu or roughly $2/ton. Considered in the context of sulfur reducing technologies that also reduce volatility, this translates into a **reduction** in willingness to pay. This suggests that it is worth exploring methods for restoring volatile matter to chars and similar products. The price effect of changed volatility could vary with other coal attributes, and should decline as the base volatility rises. Most coal burned by utilities contains 30% to 40% volatile matter. In this range, small changes in volatility probably make little difference in willingness to pay.

Preliminary analyses of the role of sulfur in the survey responses failed to identify a low-sulfur premium. This is quite different from the results of the hedonic analysis. Full explanation of the differences awaits further analysis, but two observations can be made. First, the survey elicits hypothetical intentions to purchase, not actual commit-

ments, while market transaction data reflect the latter. Because commitments are the basis of market demand, the hedonic results merit more confidence than the survey results, although they do only apply to Illinois. Second, the sulfur specifications in the survey ranged from 0.45 lb./MMBtu to 1.78 lb./MMBtu. This a small subset of the range actually observed in the market place, on the low end of the range for Illinois coal, and generally includes levels that actually or nearly comply with pollution standards. Various survey respondents commented that they do not want sulfur levels to be too low, because that would interfere with operation of emissions control equipment. The existence of little or no sulfur discount at levels of sulfur near compliance is consistent with this information.

B. LIMITATIONS AND EXTENSIONS

Several limitations are apparent in this study, and must be kept in mind as the results are considered. First, we considered only two characteristics that are particularly critical in current experimental technologies: sulfur and volatility. Insofar as other important characteristics of coal are degraded by sulfur-reducing technologies, the price benefits from removing sulfur could be at least partly offset.

Second, available data on market transactions specify a very small list of the relevant attributes: sulfur, ash, and heat content and source of the coal. These data provide an adequate (although not complete) basis for analyzing the value of sulfur, but do not help at all with respect to volatility. For that attribute, we had to generate and use data from a contingent valuation survey. The survey focused mainly on

volatility levels well below those to which most utilities are accustomed. Hence, the responses were probably somewhat speculative, and the price effects inferred from them should be interpreted with caution.

Third, the value of a change in any single attribute can be influenced by other characteristics of the coal; e.g., the value of a marginal change in sulfur could be influenced by the heat content of the coal. These cross effects must be kept in mind as the results are interpreted. Moreover, it is entirely possible that our results could be changed by the inclusion of additional characteristics in our models.

Fourth, the results presented here are preliminary and subject to a significant error. We will be undertaking more definitive analysis of these data for the CRSC and should obtain more reliable results at the conclusion of that project.

Fifth, we have only investigated existing power plants subject to existing environmental regulations. While these are important users of untreated and desulfurized Illinois coal, we are excluding new power plants from our analysis. And new power plants may prove to be major users of Illinois coal due to the required use of scrubbers.

Sixth, and finally, measuring the sulfur/volatility penalty does not indicate the <u>demand</u> for desulfurized coal. If the price is right, will one ton be sold or 100 million tons? Even if desulfurized coal betters the price targets, that does not mean significant quantities of desulfurized coal can be sold. Measuring demand is one issue which will be investigated in the upcoming CRSC project.

The reported results of both sets of analyses (the hedonic and the survey) should be regarded as preliminary. Additional efforts are under-

way to improve each. In the case of the actual market data, improvements are expected from expanding the data set to include non-Illinois transactions. Doing so awaits better procedures for dealing with spatial relationships of coal suppliers and users. The survey results will be better understood after the qualitative responses (to survey question 9) are analyzed. As indicated above, further efforts are needed to rationalize the different results for the sulfur variable in the two analyses.

C. RESEARCH IMPLICATIONS

According to our results, technologies that reduce sulfur will change the value of coal in the market place. Reducing the level of sulfur alone can produce significant positive returns, on the order of $0.70 to $1.00/MMBtu per pound of sulfur removed per million Btu of heat content. It is clear, however, that most sulfur reducing technologies degrade some attributes of coal. Of particular interest here was the effect of reducing volatile fractions, as caused by hydropyrolysis. Our results indicate a significant price penalty for such reductions, on the order of 8¢/MMBtu ($2/ton) when increasing or reducing by 10% (2.5 percentage points) a base volatility level of 25% (by weight). This suggests that significant degradation may offset much if not all of the price benefit stemming from reducing sulfur levels.

This study reinforces the need for close attention to economic considerations as research into sulfur reducing technologies is planned and implemented. At least for the steam electric utility market, attaining rock bottom levels of sulfur is not desirable. Most of the price advantages appear to accrue as compliance levels are approached. Dropping

below compliance levels earns little return; in fact, it can be a disadvantage due to losses of operating efficiencies in emission control equipment. Furthermore, changes in attributes other than sulfur (such as volatility) can be critically important. If the product cannot be handled easily or burned efficiently, it may be viewed as an inferior fuel irrespective of its sulfur level.

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APPENDIX A: SURVEY INSTRUMENT

The following is a copy of an actual survey sent to a plant in the sample (name withheld). Note that part of the survey is common to all plants in the sample and part (specifications on pages 3, 5, and 7) is tailored to the particular plant.

MARKET SURVEY FOR REDUCED-SULFUR COAL

This survey will help assess the value of processes for removing sulfur from coal. The survey should be answered by the OFFICER IN CHARGE OF FUEL SPECIFICATIONS. It is very important that all questions be answered. All responses will be held in confidence. Please return the complete survey document within five days in the attached envelope. Questions can be addressed to:

Dr. Charles Kolstad
CRSC Survey
University of Illinois
408 South Goodwin Avenue
Urbana, IL 61801

(Questions?: Contact Rodger Woock at 217/333-9897)

1. a. Name of Company:

b. Name and mailing address of officer in charge of fuel specifications:

c. If someone else is answering this survey, please give us your name:

2. Please answer questions in this survey with regard to the following generating station:

This will be called the **REFERENCE GENERATING STATION** below.

I. INFORMATION ABOUT REFERENCE GENERATING SYSTEM

3. For each UNIT of the REFERENCE GENERATING STATION please indicate your boundary (maximum or minimum) procurement specification for the following coal characteristics.

	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5
(a) Minimum BTU/lb (moisture free)					
(b) Maximum Sulfur Content (as received, measured lb/MMbtu)					
(c) Maximum Moisture Content (as received) (%)					
(d) Minimum Volatile Matter (by weight, moisture free)					
(e) Maximum Chlorine (by weight, moisture free)					
(f) Size Dispersion (Maximum % < 1/4")					
(g) Minimum Hargrove Grindability Index					
(h) Maximum Ash Content (by weight, moisture free)					
(i) Minimum T_{250} (ash fusion) Temperature (^{o}F)					
(j) Maximum T_{250} (Ash fusion) Temperature (^{o}F)					
(k) Minimum Ash Resistivity (ohms-cm)					
(l) Maximum Base/Acid Ratio of Ash					
(m) Maximum Fouling Index Computed Using $Na_2O - K_2O$					
(n) Maximum Na_2O as % of Ash Mineral Analysis					
(o) Maximum % Alkaline as Na_2O, Dry Basis					
(p) Maximum Slagging Index					

4. According to data from FERC Form 423, your major purchases of coal in late 1986 were, for plant :

DATE	SOURCE	QUANTITY(T)	SULFUR(%)	ASH(%)	PRICE(c)
10/86	CARTER MINING CO	415400	0.34	4.80	198.30
10/86	CARTER MINING CO	54700	0.34	4.80	198.50
11/86	CARTER MINING CO	367300	0.29	4.70	197.10
11/86	CARTER MINING CO	107100	0.29	4.70	197.10

5. The quantity weighted average price of the coal bought during that period was 197.71 c/MMBtu. For purposes of this survey, this price is referred to below as your REFERENCE PRICE. The quantity weighted average sulfur content of the coal was 0.31 %. The quantity weighted average ash content was 4.75 %.

6. To the best of your knowledge, what was the average volatile content (% weight, dry-basis) of the purchases during this period? (Calculate the quantity weighted average as the sum of the product of the volatility % times the quantity of each shipment divided by the total quantity received during the period.)

_____%

II. REDUCED-SULFUR SOLID FUELS

A reduced-sulfur solid fuel product is described below. Following the description, other characteristics and delivery conditions are listed. After carefully reading these descriptions, you will be asked to indicate how much of this product you would purchase for a particular price differential relative to the REFERENCE PRICE established above.

PRODUCT CHARACTERIZATION

	% Weight			% Weight
Proximate Analysis	As Rec'd	Dry Basis	Ultimate Analysis	Dry Basis
Moisture	6.57	N/A	Moisture	N/A
Ash	/	9.32	Carbon	76.81
Volatile	/	35.26	Hydrogen	4.92
Fixed Carbon	/	55.42	Nitrogen	1.75
		-------	Chlorine	0.10
		100%	Sulfur	0.95
			Ash	9.32
Btu/lb.	/	13,827	Oxygen (diff)	6.15
Sulfur	/	0.95		------
Alk. as Na_2O	/	0.18		100%

Ash Fusion	Reducing (°F)	Mineral Analysis of Ash	% Weight Ignited Basis
Initial Deform.	2700+	Silica, SiO_2	53.10
Softening (H-W)	2700+	Alumina, Al_2O_3	29.95
Softening (H-1/2W)	2700+	Titania, TiO_2	1.47
Fluid	2700+	Ferric Oxide, Fe_2O_3	7.31
T_{250} Temp.	2900+	Lime, CaO	2.24
		Magnesia, MgO	1.13
		Potassium Oxide, K_2O	2.75
% Equilibrium Moisture	4.5	Sodium Oxide, Na_2O	0.79
Silica Value	83.25	Sulfur Trioxide, SO_3	0.72
Base: Acid Ratio	0.17	Phos. Pentoxide, P_2O_5	0.12
Free-Swelling Index	5	Strontium Oxide, SrO	0.19
Hardgrove Grind-	48@4.5%	Barium Oxide, BaO	0.12
ability Index	Moisture	Manganese Oxide, Mn_3O_4	0.08
Fouling Index	0.09	Undetermined	0.03
Slagging Index	0.10		-------
			100%

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ADDITIONAL CHARACTERISTICS AND DELIVERY CONDITIONS

It is **VERY IMPORTANT** that you envision the following conditions of this product and your purchase of it:

[A.] It is available from a reputable and reliable supplier.

[B.] It will be delivered in rail cars or barges according to the usual specifications for the REFERENCE STATION.

[C.] It can be handled satisfactorily in available conveyors, blenders, pulverizers, etc. Its vulnerability to freezing, oxidation, and spontaneous combustion is well within industry norms.

[D.] The stated price will be subject to usual premia or penalties for variations away from the specifications listed above and you can specify rejection limits.

[E.] You are able to curtail purchases of other fuels without being penalized or jeopardizing your ability to purchase those fuels in the future.

[F.] Air pollution control regulations will remain at current levels.

PLEASE BE IMAGINATIVE AND FLEXIBLE IN CONSIDERING WHETHER THIS FUEL COULD BE ATTRACTIVE AT THE RIGHT PRICE FOR PART OF YOUR FUEL PURCHASES.

III. BIDDING FOR THE REDUCED-SULFUR FUEL

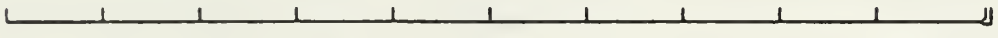
Most fuel procurement is done by competitive bidding. Each bid provides a price and list of coal qualities and you are able to choose among the bids. The format here is different. You are given a price for the reduced sulfur product and asked how much you would purchase. You can choose any amount, from 0% of your total 1986 coal requirement to 100%. You should purchase some of this product if, by substituting it for some or all of your other coal, you can reduce the busbar cost of generating electricity.

7. Suppose that the reduced-sulfur fuel is offered in spot or long-term contracts at 86.5 % of the REFERENCE PRICE (developed in point 5 above).

   This would make its price

   86.5 % x 197.71 ¢/MMbtu = 170.96 ¢/MMbtu

   At this price, approximately how much of this fuel (as a percentage of your 1986-coal usage) would you buy? (Use an "x" to mark one point on the following scale)

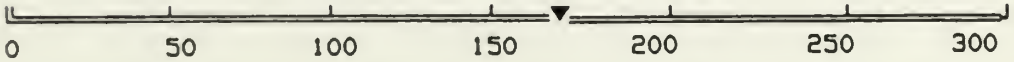


0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

8. Was your answer 0% to the preceding question? (Circle one response) YES NO

   If NO: Go to question 9

   If YES: Relative to late 1986 coal prices, at what price would it be worthwhile to buy enough of this product to make up 5% of your fuel purchases (in tons)? (Use an "x" to mark one point on the following scale. Your reference price is indicated by ▼.)



0 50 100 150 200 250 300

¢/MMBTU

9. For the product specified above, rate the following non-price characteristics as negative or positive influences on your overall evaluation of the quality of the product.

	Very Negative			Very Positive
a) Volatility	1	2	3	4
b) Combustibility	1	2	3	4
c) Handling characteristics	1	2	3	4
d) Sulfur content	1	2	3	4
e) Ash content	1	2	3	4
f) Ash fusion	1	2	3	4
g) Ash resistivity	1	2	3	4
h) Alkaline content	1	2	3	4
i) Chlorine	1	2	3	4
j) Fouling	1	2	3	4
k) Slagging	1	2	3	4
l) Supply reliability	1	2	3	4
m) Contract terms	1	2	3	4
n) Compliance with current SIP	1	2	3	4
o) Possible changes in pollution standards	1	2	3	4

10. If you have additional comments about this survey, please write them below:

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

PLEASE RETURN THIS SURVEY IN THE ATTACHED, ADDRESSED AND STAMPED ENVELOPE WITHIN FIVE DAYS. RETURN TO:

Dr. Charles Kolstad
CRSC Survey
University of Illinois
408 South Goodwin Avenue
Urbana, IL 61801

(Questions? Contact Rodger Woock at 217/333-9897)

THANK YOU FOR YOUR COOPERATION.

APPENDIX B: RAW SURVEY DATA

This appendix summarizes the survey answers.

Table B-I contains most of the raw survey data. Each line of the table corresponds to a different power plant. Power plants are not identified to protect confidentiality. The table summarizes all the information elicited (columns 4, 11) and conveyed (columns 1, 2, 3, 5, 6, 7, 8, 9) by the survey instrument with exception of the answers to question 9. Column 10 is generally conveyed and sometimes elicited.

In Tables B-II, B-III and B-IV, summary statistics of the data in Table B-I are presented.

Table B-V summarizes the answers to question 9 of the survey and Table B-VI presents selected comments on the survey.

Finally, Figure B-1 describes the distribution of the sample by state.

TABLE B-I: RAW SURVEY DATA

REFERENCE ATTRIBUTES				TREATMENTS					RESPONSES	
(1) PRICE (¢/MMbtu)	(2) SULFUR (% weight)	(3) ASH (% weight)	(4) VOLATILITY (% weight)	(5) SULFUR (% weight)	(6) VOLATILITY (% weight)	(7) ASH (% weight)	(8) T_{250} (^{o}F)	(9) BTU (per lb)	(10) PRICE (¢/MMBtu)	(11) QUANTITY DESIRED (% current burn)
139.00	.80	12.30	31.5	.45	35.26	9.32	1	13,859	134.53	10.0
195.00	.93	12.49	31.5	1.78	15.12	9.32	1	13,532	177.99	0.0
197.62	1.83	11.84	33	.95	25.14	9.32	1	13,754	217.65	0
186.29	1.09	6.64	44	.95	35.26	2.13	0	14,927	31.27	0
126.58	2.33	8.45	37.50	.45	25.14	9.32	1	13,782	39.49	20.0
113.48	2.94	10.11	N/A	.95	15.12	2.13	0	14,700	146.60	0
143.37	2.79	5.84	33-37	.95	15.12	9.32	1	13,612	180.99	0
174.26	3.78	9.34	41.6	.45	15.12	2.13	0	14,721	177.87	0
143.57	3.44	10.16	42	.45	25.14	2.13	0	14,867	121.92	6
288.44	.45	4.99	42	1.78	35.26	2.13	0	14,834	57.69	0
357.85	.46	6.71	37-42	1.78	15.12	9.32	1	13,532	137.08	0
286.25	.43	4.84	41	.95	25.14	2.13	0	14,867	185.26	10
179.58	.85	10.93	33	1.78	35.26	9.32	1	13,744	127.97	50
183.14	1.22	9.66	33	.95	15.12	2.13	0	14,700	140.00	5
140.70	1.60	6.0	36	1.78	25.14	9.32	1	13,670	132.70	25

TABLE B-I: RAW SURVEY DATA (CONT'D)

REFERENCE ATTRIBUTES				TREATMENTS					RESPONSES	
PRICE (¢/MMbtu)	SULFUR (% weight)	ASH (% weight)	VOLATILITY (% weight)	SULFUR (% weight)	VOLATILITY (% weight)	ASH (% weight)	T_{250} (^{o}F)	BTU (per lb)	PRICE (¢/MMBtu)	QUANTITY DESIRED (% current burn)
113.34	1.64	11.56	N/A	1.78	35.26	9.32	1	13,744	100.08	50.0
114.1	2.85	11.00	N/A	.95	15.12	9.32	1	13,612	183.04	0
178.53	1.91	9.19	N/A	.45	15.12	9.32	1	13,626	187.89	0
124.21	5.10	19.34	35.00	1.78	15.12	2.13	0	14,606	130.00	5
181.70	.80	8.75	35.5	.95	35.26	9.32	1	13,827	125.00	5
169.32	.79	5.70	34	.45	35.26	9.32	1	13,859	170.0	5
165.70	1.72	10.02	37	1.78	15.12	9.32	1	13,532	102.59	0
176.40	2.28	10.25	38	.45	25.14	9.32	1	13,782	167.02	0
163.37	2.42	8.28	40	.95	15.12	9.32	1	13,612	176.78	0
183.25	2.84	9.21	39.33	1.78	25.14	9.32	1	13,670	90.0	5
128.52	2.59	9.09	34	1.78	35.26	9.32	1	13,744	50.0	5
149.39	2.60	10.25	39	.45	35.26	2.13	0	14,952	257.40	0
140.08	.64	10.47	36-38	.45	15.12	9.32	1	13,626	151.96	0
135.15	2.47	8.50	39	.45	35.26	9.32	1	13,859	86.01	0
90.30	.38	5.48	N/A	1.78	15.12	9.32	1	13,532	18.06	0
108.17	.32	5.87	N/A	.95	25.14	9.32	1	13,754	66.0	5

TABLE B-I: RAW SURVEY DATA (CONT'D)

REFERENCE ATTRIBUTES				TREATMENTS					RESPONSES	
PRICE (¢/MMbtu)	SULFUR (% weight)	ASH (% weight)	VOLATILITY (% weight)	SULFUR (% weight)	VOLATILITY (% weight)	ASH (% weight)	T_{250} (^{o}F)	BTU (per lb)	PRICE (¢/MMBtu)	QUANTITY DESIRED (% current burn)
103.98	.40	5.81	N/A	.95	15.12	9.32	1	13,612	20.8	0
88.8	.30	9.87	32.4	1.78	25.14	9.32	1	13,670	70.0	5
175.14	.82	9.80	42	1.78	35.26	9.32	1	13,744	110.0	5
213.32	1.45	10.79	36.04	.95	35.26	9.32	1	13,827	163.0	100
197.53	.83	7.12	34.0	.45	35.26	9.32	1	13,859	186.22	0
166.67	1.24	7.26	730.00	1.78	15.12	2.13	0	14,606	142.37	10
187.26	2.43	11.36	40	.45	15.12	2.13	0	14,721	91.47	25.0
181.73	3.26	10.02	36	.45	35.26	9.32	1	13,859	168.33	0
151.62	3.00	11.49	N/A	.45	25.14	9.32	1	13,782	100.0	5
208.31	1.75	7.36	N/A	.95	35.26	9.32	1	13,827	205.84	0
161.72	.88	8.84	32.7(ar)	.45	25.14	9.32	1	13,782	161.72	0
106.01	3.68	15.78	N/A	1.78	35.26	2.13	0	14,834	90.0	5
146.25	2.19	9.21	N/A	1.78	25.14	9.32	1	13,670	102.26	100
155.5	1.16	6.80	39.57	1.78	35.26	2.13	0	14,834	163.43	5
132.27	3.48	11.31	41.48	1.78	35.26	9.32	1	13,744	144.53	0
229.88	1.01	5.86	42.4	.95	15.12	2.13	0	14,700	202.72	0

TABLE B-I: RAW SURVEY DATA (CONT'D)

REFERENCE ATTRIBUTES				TREATMENTS					RESPONSES	
PRICE (¢/MMbtu)	SULFUR (% weight)	ASH (% weight)	VOLATILITY (% weight)	SULFUR (% weight)	VOLATILITY (% weight)	ASH (% weight)	T_{250} (°F)	BTU (per lb)	PRICE (¢/MMBtu)	QUANTITY DESIRED (% current burn)
141.57	1.03	9.03	33	.45	15.12	9.32	1	13,626	168.34	13
137.20	2.75	8.53	38	.95	35.26	9.32	1	13,827	128.55	65
120.85	1.78	9.55	33	.45	35.26	9.32	1	13,859	125.00	5
149.68	1.14	12.26	35	1.78	15.12	9.32	1	13,532	139.72	37
158.55	2.45	8.82	32.5(ar)	.95	25.14	9.32	1	13,754	281.32	0
182.08	1.06	10.53	29.5(ar)	.45	25.14	9.32	1	13,782	191.90	0
161.53	.89	9.12	37.5	1.78	15.12	2.13	0	14,606	172.68	0
166.73	1.48	7.28	35.0	.95	15.12	9.32	1	13,612	135.66	0
139.16	.30	5.78	41.94	1.78	25.14	9.32	1	13,670	27.83	0
199.12	.40	4.82	43.5	1.78	35.26	9.32	1	13,744	197.24	30
173.64	1.27	10.41	36	.95	25.14	9.32	1	13,754	80.00	5
169.87	2.53	10.20	38.34	.45	25.14	2.13	0	14,867	172.33	-
185.76	3.28	10.22	N/A	.95	25.14	2.13	0	14,848	37.50	0
142.00	.25	4.46	32.00	1.78	15.12	9.32	1	13,532	80.00	5
124.54	1.66	8.13	43.00	.45	25.14	2.13	0	14,867	95.64	5

Key to Table B-I:

(1), (2), (3): Quantity weighted, averages of prices, sulfur and ask of late 1986 purchases. Source: FERC form 423 (cf. page 3 of the survey)

(4): Quantity weighted average of volatility (dry basis) in late 1986 purchases. Source: Answers to question 6 (page 4)

(5), (6), (7), (8), (9): Characteristics of the offered fuels (cf page 5 of the survey) (dry basis).
A "1" in column (8) means T_{250}-2900_{+} and a "0" T_{250}-2380.

(10): Price of the offered fuel (cf page 7 of the survey)

(11): Quantity purchased as % of current coal usage. A "0" reflects a zero answer to both questions 7 and 8. Where the answer to question 7 was zero but a price was indicated in question 8, 5% was recorded in which (11) and that price was considered in column (10).

TABLE B-II. SUMMARY STATISTICS
(Mean, Standard Deviation, Range)

Number of answers: 62

		MEAN	ST. DEV	MIN.	MAX.
Reference Attributes	Price	163.47	46.09	88.80	357.85
	Sulfur	1.72	1.10	0.25	5.10
	Ash	8.94	2.76	4.46	19.34
	Volatility(*)	37.21	3.76	31.50	44.00
Treatment	Sulfur	1.10	.57	0.45	1.78
	Volatility	25.01	8.45	15.12	35.26
	T(**)	.71	-	-	-
	Ash	7.23	3.29	2.13	9.32
	Price	132.70	57.21	18.06	281.32
	Purchases	10.18	21.28	0	100
	Purchases > 0	51.61	_	_	_
	SD(***)	66.13	_	_	_
	VD(****)	61.29	_	_	_

(*) Computed over the 47 answers to question 6 of the survey (only "dry basis" answers were considered)

(**) T = 1 if $T_{250} = 2900_{+}{}^{o}F$ and T = 0 if $T_{250} = 2380^{o}F$

(***) SD = 1 if sulfur treatment ≤ reference sulfur, 0 otherwise. (So Mean(SD) roughly indicates the proportion of cases for which the offered fuel was compliance)

(****) VD = 1 if volatility treatment ≤ min volatility specification (cf p 2), 0 otherwise
(So Mean VD indicates the proportion of plants for which the technological constraint on volatility level was binding)

TABLE B-III: COVARIANCE MATRIX OF VARIABLES

	RP	RS	RA	S	V	A	T	SD	I	ESP	P	Q
RP	2124.1											
RS	-12.67	1.19										
RA	-24.68	1.89	7.60									
S	.55	-.11	-.089	.32								
V	11.36	.023	-.12	-.14	71.45							
A	-22.82	-.95	-1.08	.078	3.21	10.83						
T	-3.17	-.13	-.15	.011	.45	1.51	.21					
SD	-2.55	.32	.51	-.18	.27	-.13	-.018	.21				
I	-4.09	-.044	.20	.067	.91	.034	.0048	-.052	.25			
ESP	1.84	.12	.24	-0.044	.78	-.11	-.015	-.0040	.045	.20		
P	751.46	7.80	23.86	-9.11	-17.98	-3.25	-.45	7.08	-6.69	-3.19	3262.8	
Q	-19.36	-.29	6.60	2.37	41.30	12.64	1.78	-.46	5.07	2.21	-65.57	452.90

TABLE B-IV: CORRELATION MATRIX OF VARIABLES

	RP	RS	RA	S	V	A	T	SD	I	ESP	P	Q
RP	1.00											
RS	-.25	1.00										
RA	-.19	.62	1.00									
S	.021	-.18	-.056	1.00								
V	.029	.0025	-.0053	-.029	1.00							
A	-.15	-.26	-.12	.042	.12	1.00						
T	-.15	-.26	-.12	.042	.12	1.00	1.00					
SD	-.12	.61	.39	-.67	.06	-.082	-.082	1.00				
I	-.18	-.080	.14	.24	.21	.021	.021	-.22	1.00			
ESP	.089	.25	.20	.17	.21	-.075	-.075	.018	.20	1.00		
P	.29	.12	.15	-.28	-.037	-.017	-.017	.26	-.23	-.12	1.00	
Q	-.020	-.013	.11	.20	.23	.18	.18	-.045	.47	.23	-.054	1.00

TABLE B-V: ANSWERS TO QUESTION 9
(cell frequencies and row means)

	Very Negative			Very Positive	
	1	2	3	4	MEAN SCORE
a) Volatility	29	6	21	5	2
b) Combustibility	18	10	20	10	2
c) Handling characteristics	8	10	28	11	3
d) Sulfur content	15	9	17	22	3
e) Ash content	4	16	27	16	3
f) Ash fusion	6	6	25	22	3
g) Ash resistivity	15	16	10	5	2
h) Alkaline content	0	12	32	5	3
i) Chlorine	1	14	29	8	3
j) Fouling	1	5	27	22	3
k) Slagging	4	6	27	19	3
l) Supply reliability	0	3	23	28	3
m) Contract terms	3	9	24	17	3
n) Compliance with current SIP	9	5	19	18	3
o) Possible changes in pollution standards	14	5	23	18	3

TABLE B-VI: Selected Answers to Question 10

"Qualification of the answers provided are subject to a required test burn at plants designated and more detailed information as to nature of product specified."

"Volatile matter is less than desired. All other answers are qualified based on test shipments and additional information as to the nature of the product specified."

"Any additional fuel supplies for the units other than contract coals are competitively bid on the spot market. Our weight average cost includes both spot and contract. Any new fuel would be competing, at least for a time, with spot market coal prices."

"The survey information as provided is extremely ambiguous, offering conjectural and abstract characteristics, descriptions and conditions. It is impossible to answer knowledgeably to this survey given the general concepts it offers as applied to a highly technical function of fuel economic evaluation, for procurement. Evaluation on plant performance, cost, delivery costs, calculated combustion test, full-scale test burns, engineering studies, and computerized impact sensitivity analysis would have to be conducted and known prior to addressing this survey."

"Would probably be willing to purchase quantity to test coal but have concerns about potential problems with dustiness, low volatility, marginal sulfur level and low ash resistivity."

"Units ... are cyclone fired boilers, too low volatile content and ash for cyclone operation. Sulfur content too low. Precipitators would not operate properly due to resistivity, therefore, some type of flue gas conditioning would have to be installed. Iron to calcium ratio indicates that furnace slagging could be a problem. At a price of 91.47 c/MMBtu (delivered), this coal could be blended to offset negative effects of this coal while taking advantage of low price."

"Main concern is low volatile content (15%). This low a value would probably require supplemental oil firing at high load to assure flame stability and carbon burnout. Also have concerns about size consist and friability if it is a highly processed coal (chemical desulfurization). A test burn is the only way to know for sure."

" 5% isn't worthwhile."

"Would require additional precipitator expenses - sulfur too low for these units to meet opacity standard."

"No such price exists." (At which respondent would buy any coal).

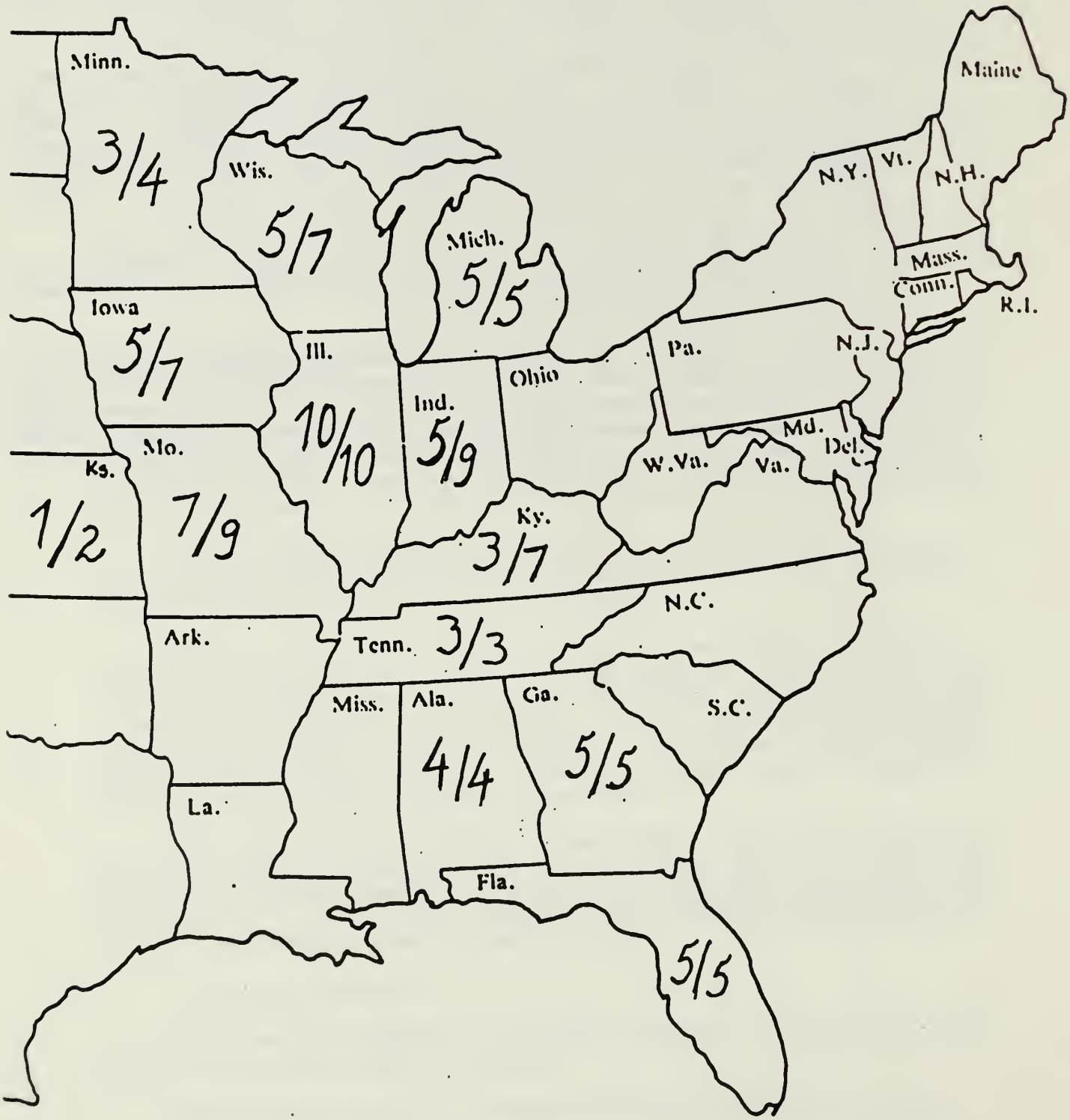
"Our experience burning petroleum coke which has very low volatile

content is not good. Our furnaces did not completely burn the low volatile coke and we had higher than average unburned combustibles in the ash. In addition the unburned carbon was not readily collected by our electrostatic precipitators."

"The only way this fuel can be evaluated is by test burning at the facility in question. There is considerable uncertainty that the volatile matter specification are within tolerable limits. It should also be noted that it would take a combustion engineer to properly respond to many of the questions. Since we do not have an "in-house" combustion expert, our response probably reflects this lack of expertise."

"May be willing to test coal but concerned about low volatility, low ash resistivity and relatively small price differential. Also low moisture content may present dust problems."

"The ... plant is an older plant that does not have any desulfurization systems. Our present coal supply easily meets EPA guidelines for sulfur emissions, so there would be no advantage to buying low sulfur coal, unless the price would be lower than our present supply. Looking at the specs on this coal it appears that it would work adequately in our boilers."



Key: x/y = (number of answers received)/(number of questionnaires sent)

Figure B-1: Geographic Distribution of Survey Sample

APPENDIX C: ALTERNATE FUELS

This appendix contains the ultimate and proximate analyses of the 18 different fuels offered to plants in the sample (only one to each plant).

II. REDUCED-SULFUR SOLID FUELS

A reduced-sulfur solid fuel product is described below. Following the description, other characteristics and delivery conditions are listed. After carefully reading these descriptions, you will be asked to indicate how much of this product you would purchase for a particular price differential relative to the REFERENCE PRICE established above.

PRODUCT CHARACTERIZATION

	% Weight			% Weight
Proximate Analysis	As Rec'd	Dry Basis	Ultimate Analysis	Dry Basis
Moisture	6.57	N/A	Moisture	N/A
Ash	/	2.13	Carbon	86.37
Volatile	/	15.12	Hydrogen	3.89
Fixed Carbon	/	82.75	Nitrogen	1.91
		-------	Chlorine	0.10
		100%	Sulfur	0.95
			Ash	2.13
Btu/lb.	/	14,700	Oxygen (diff)	4.65
Sulfur	/	0.95		------
Alk. as Na_2O	/	0.18		100%

Ash Fusion	Reducing (°F)
Initial Deform.	2025
Softening (H=W)	2185
Softening (H=1/2W)	2320
Fluid	2365
T_{250} Temp.	2380
% Equilibrium Moisture	4.5
Silica Value	65.51
Base: Acid Ratio	0.39
Free-Swelling Index	5
Hardgrove Grindability Index	48@4.5% Moisture
Fouling Index	0.20
Slagging Index	0.95

Mineral Analysis of Ash	% Weight Ignited Basis
Silica, SiO_2	48.41
Alumina, Al_2O_3	21.14
Titania, TiO_2	1.25
Ferric Oxide, Fe_2O_3	22.10
Lime, CaO	1.87
Magnesia, MgO	0.93
Potassium Oxide, K_2O	2.46
Sodium Oxide, Na_2O	0.54
Sulfur Trioxide, SO_3	0.72
Phos. Pentoxide, P_2O_5	0.28
Strontium Oxide, SrO	0.07
Barium Oxide, BaO	0.03
Manganese Oxide, Mn_3O_4	0.00
Undetermined	0.00

	100%

II. REDUCED-SULFUR SOLID FUELS

A reduced-sulfur solid fuel product is described below. Following the description, other characteristics and delivery conditions are listed. After carefully reading these descriptions, you will be asked to indicate how much of this product you would purchase for a particular price differential relative to the REFERENCE PRICE established above.

PRODUCT CHARACTERIZATION

	% Weight			% Weight
Proximate Analysis	As Rec'd	Dry Basis	Ultimate Analysis	Dry Basis
Moisture	6.57	N/A	Moisture	N/A
Ash	/	2.13	Carbon	85.60
Volatile	/	15.12	Hydrogen	3.86
Fixed Carbon	/	82.75	Nitrogen	1.92
		-------	Chlorine	0.10
		100%	Sulfur	1.78
			Ash	2.13
Btu/lb.	/	14,606	Oxygen (diff)	4.61
Sulfur	/	1.78		------
Alk. as Na_2O	/	0.18		100%

Ash Fusion	Reducing (°F)	Mineral Analysis of Ash	% Weight Ignited Basis
Initial Deform.	2025	Silica, SiO_2	48.41
Softening (H-W)	2185	Alumina, Al_2O_3	21.14
Softening (H-1/2W)	2320	Titania, TiO_2	1.25
Fluid	2365	Ferric Oxide, Fe_2O_3	22.10
T_{250} Temp.	2380	Lime, CaO	1.87
		Magnesia, MgO	0.93
		Potassium Oxide, K_2O	2.46
% Equilibrium Moisture	4.5	Sodium Oxide, Na_2O	0.54
Silica Value	65.51	Sulfur Trioxide, SO_3	0.72
Base: Acid Ratio	0.39	Phos. Pentoxide, P_2O_5	0.28
Free-Swelling Index	5	Strontium Oxide, SrO	0.07
Hardgrove Grind-ability Index	48@4.5% Moisture	Barium Oxide, BaO	0.03
		Manganese Oxide, Mn_3O_4	0.00
Fouling Index	0.20	Undetermined	0.00
Slagging Index	0.95		-------
			100%

II. REDUCED-SULFUR SOLID FUELS

A reduced-sulfur solid fuel product is described below. Following the description, other characteristics and delivery conditions are listed. After carefully reading these descriptions, you will be asked to indicate how much of this product you would purchase for a particular price differential relative to the REFERENCE PRICE established above.

PRODUCT CHARACTERIZATION

	% Weight			% Weight
Proximate Analysis	As Rec'd	Dry Basis	Ultimate Analysis	Dry Basis
Moisture	6.57	N/A	Moisture	N/A
Ash	/	2.13	Carbon	84.90
Volatile	/	25.14	Hydrogen	4.66
Fixed Carbon	/	72.73	Nitrogen	2.14
		-------	Chlorine	0.10
		100%	Sulfur	0.45
			Ash	2.13
Btu/lb.	/	14,867	Oxygen (diff)	5.62
Sulfur	/	0.45		------
Alk. as Na_2O	/	0.18		100%

Ash Fusion	Reducing (°F)
Initial Deform.	2025
Softening (H=W)	2185
Softening (H=1/2W)	2320
Fluid	2365
T_{250} Temp.	2380
% Equilibrium Moisture	4.5
Silica Value	65.51
Base: Acid Ratio	0.39
Free-Swelling Index	5
Hardgrove Grindability Index	48@4.5% Moisture
Fouling Index	0.20
Slagging Index	0.95

Mineral Analysis of Ash	% Weight Ignited Basis
Silica, SiO_2	48.41
Alumina, Al_2O_3	21.14
Titania, TiO_2	1.25
Ferric Oxide, Fe_2O_3	22.10
Lime, CaO	1.87
Magnesia, MgO	0.93
Potassium Oxide, K_2O	2.46
Sodium Oxide, Na_2O	0.54
Sulfur Trioxide, SO_3	0.72
Phos. Pentoxide, P_2O_5	0.28
Strontium Oxide, SrO	0.07
Barium Oxide, BaO	0.03
Manganese Oxide, Mn_3O_4	0.00
Undetermined	0.00

	100%

II. REDUCED-SULFUR SOLID FUELS

A reduced-sulfur solid fuel product is described below. Following the description, other characteristics and delivery conditions are listed. After carefully reading these descriptions, you will be asked to indicate how much of this product you would purchase for a particular price differential relative to the REFERENCE PRICE established above.

PRODUCT CHARACTERIZATION

	% Weight	
Proximate Analysis	As Rec'd	Dry Basis
Moisture	6.57	N/A
Ash	/	2.13
Volatile	/	25.14
Fixed Carbon	/	72.73
		100%
Btu/lb.	/	14,848
Sulfur	/	0.95
Alk. as Na_2O	/	0.18

	% Weight
Ultimate Analysis	Dry Basis
Moisture	N/A
Carbon	84.66
Hydrogen	4.65
Nitrogen	1.91
Chlorine	0.10
Sulfur	0.95
Ash	2.13
Oxygen (diff)	5.60
	100%

Ash Fusion	Reducing (°F)
Initial Deform.	2025
Softening (H=W)	2185
Softening (H=1/2W)	2320
Fluid	2365
T_{250} Temp.	2380
% Equilibrium Moisture	4.5
Silica Value	65.51
Base: Acid Ratio	0.39
Free-Swelling Index	5
Hardgrove Grindability Index	48@4.5% Moisture
Fouling Index	0.20
Slagging Index	0.95

Mineral Analysis of Ash	% Weight Ignited Basis
Silica, SiO_2	48.41
Alumina, Al_2O_3	21.14
Titania, TiO_2	1.25
Ferric Oxide, Fe_2O_3	22.10
Lime, CaO	1.87
Magnesia, MgO	0.93
Potassium Oxide, K_2O	2.46
Sodium Oxide, Na_2O	0.54
Sulfur Trioxide, SO_3	0.72
Phos. Pentoxide, P_2O_5	0.28
Strontium Oxide, SrO	0.07
Barium Oxide, BaO	0.03
Manganese Oxide, Mn_3O_4	0.00
Undetermined	0.00
	100%

II. REDUCED-SULFUR SOLID FUELS

A reduced-sulfur solid fuel product is described below. Following the description, other characteristics and delivery conditions are listed. After carefully reading these descriptions, you will be asked to indicate how much of this product you would purchase for a particular price differential relative to the REFERENCE PRICE established above.

PRODUCT CHARACTERIZATION

	% Weight	
Proximate Analysis	As Rec'd	Dry Basis
Moisture	6.57	N/A
Ash	/	2.13
Volatile	/	25.14
Fixed Carbon	/	72.73
		100%
Btu/lb.	/	14,751
Sulfur	/	1.78
Alk. as Na_2O	/	0.18

	% Weight
Ultimate Analysis	Dry Basis
Moisture	N/A
Carbon	83.91
Hydrogen	4.61
Nitrogen	1.92
Chlorine	0.10
Sulfur	1.78
Ash	2.13
Oxygen (diff)	5.55
	100%

Ash Fusion	Reducing (°F)
Initial Deform.	2025
Softening (H=W)	2185
Softening (H=1/2W)	2320
Fluid	2365
T_{250} Temp.	2380
% Equilibrium Moisture	4.5
Silica Value	65.51
Base: Acid Ratio	0.39
Free-Swelling Index	5
Hardgrove Grindability Index	48@4.5% Moisture
Fouling Index	0.20
Slagging Index	0.95

Mineral Analysis of Ash	% Weight Ignited Basis
Silica, SiO_2	48.41
Alumina, Al_2O_3	21.14
Titania, TiO_2	1.25
Ferric Oxide, Fe_2O_3	22.10
Lime, CaO	1.87
Magnesia, MgO	0.93
Potassium Oxide, K_2O	2.46
Sodium Oxide, Na_2O	0.54
Sulfur Trioxide, SO_3	0.72
Phos. Pentoxide, P_2O_5	0.28
Strontium Oxide, SrO	0.07
Barium Oxide, BaO	0.03
Manganese Oxide, Mn_3O_4	0.00
Undetermined	0.00
	100%

II. REDUCED-SULFUR SOLID FUELS

A reduced-sulfur solid fuel product is described below. Following the description, other characteristics and delivery conditions are listed. After carefully reading these descriptions, you will be asked to indicate how much of this product you would purchase for a particular price differential relative to the REFERENCE PRICE established above.

PRODUCT CHARACTERIZATION

	% Weight			% Weight
Proximate Analysis	As Rec'd	Dry Basis	Ultimate Analysis	Dry Basis
Moisture	6.57	N/A	Moisture	N/A
Ash	/	2.13	Carbon	83.19
Volatile	/	35.26	Hydrogen	5.33
Fixed Carbon	/	62.61	Nitrogen	2.14
		-------	Chlorine	0.10
		100%	Sulfur	0.45
			Ash	2.13
Btu/lb.	/	14,952	Oxygen (diff)	6.66
Sulfur	/	0.45		------
Alk. as Na_2O	/	0.18		100%

Ash Fusion	Reducing (°F)	Mineral Analysis of Ash	% Weight Ignited Basis
Initial Deform.	2025	Silica, SiO_2	48.41
Softening (H-W)	2185	Alumina, Al_2O_3	21.14
Softening (H-1/2W)	2320	Titania, TiO_2	1.25
Fluid	2365	Ferric Oxide, Fe_2O_3	22.10
T_{250} Temp.	2380	Lime, CaO	1.87
		Magnesia, MgO	0.93
		Potassium Oxide, K_2O	2.46
% Equilibrium Moisture	4.5	Sodium Oxide, Na_2O	0.54
Silica Value	65.51	Sulfur Trioxide, SO_3	0.72
Base: Acid Ratio	0.39	Phos. Pentoxide, P_2O_5	0.28
Free-Swelling Index	5	Strontium Oxide, SrO	0.07
Hardgrove Grind-ability Index	48@4.5% Moisture	Barium Oxide, BaO	0.03
		Manganese Oxide, Mn_3O_4	0.00
Fouling Index	0.20	Undetermined	0.00
Slagging Index	0.95		-------
			100%

II. REDUCED-SULFUR SOLID FUELS

A reduced-sulfur solid fuel product is described below. Following the description, other characteristics and delivery conditions are listed. After carefully reading these descriptions, you will be asked to indicate how much of this product you would purchase for a particular price differential relative to the REFERENCE PRICE established above.

PRODUCT CHARACTERIZATION

	% Weight	
Proximate Analysis	As Rec'd	Dry Basis
Moisture	6.57	N/A
Ash	/	2.13
Volatile	/	35.26
Fixed Carbon	/	62.61
		100%
Btu/lb.	/	14,927
Sulfur	/	0.95
Alk. as Na_2O	/	0.18

	% Weight
Ultimate Analysis	Dry Basis
Moisture	N/A
Carbon	82.95
Hydrogen	5.31
Nitrogen	1.92
Chlorine	0.10
Sulfur	0.95
Ash	2.13
Oxygen (diff)	6.64
	100%

Ash Fusion	Reducing (°F)
Initial Deform.	2025
Softening (H-W)	2185
Softening (H-1/2W)	2320
Fluid	2365
T_{250} Temp.	2380
% Equilibrium Moisture	4.5
Silica Value	65.51
Base: Acid Ratio	0.39
Free-Swelling Index	5
Hardgrove Grindability Index	48@4.5% Moisture
Fouling Index	0.20
Slagging Index	0.95

Mineral Analysis of Ash	% Weight Ignited Basis
Silica, SiO_2	48.41
Alumina, Al_2O_3	21.14
Titania, TiO_2	1.25
Ferric Oxide, Fe_2O_3	22.10
Lime, CaO	1.87
Magnesia, MgO	0.93
Potassium Oxide, K_2O	2.46
Sodium Oxide, Na_2O	0.54
Sulfur Trioxide, SO_3	0.72
Phos. Pentoxide, P_2O_5	0.28
Strontium Oxide, SrO	0.07
Barium Oxide, BaO	0.03
Manganese Oxide, Mn_3O_4	0.00
Undetermined	0.00
	100%

II. REDUCED-SULFUR SOLID FUELS

A reduced-sulfur solid fuel product is described below. Following the description, other characteristics and delivery conditions are listed. After carefully reading these descriptions, you will be asked to indicate how much of this product you would purchase for a particular price differential relative to the REFERENCE PRICE established above.

PRODUCT CHARACTERIZATION

	% Weight			% Weight
Proximate Analysis	As Rec'd	Dry Basis	Ultimate Analysis	Dry Basis
Moisture	6.57	N/A	Moisture	N/A
Ash	/	2.13	Carbon	82.22
Volatile	/	35.26	Hydrogen	5.27
Fixed Carbon	/	62.61	Nitrogen	1.92
		-------	Chlorine	0.10
		100%	Sulfur	1.78
			Ash	2.13
Btu/lb.	/	14,834	Oxygen (diff)	6.58
Sulfur	/	1.78		------
Alk. as Na_2O	/	0.18		100%

Ash Fusion	Reducing (°F)	Mineral Analysis of Ash	% Weight Ignited Basis
Initial Deform.	2025	Silica, SiO_2	48.41
Softening (H-W)	2185	Alumina, Al_2O_3	21.14
Softening (H-1/2W)	2320	Titania, TiO_2	1.25
Fluid	2365	Ferric Oxide, Fe_2O_3	22.10
T_{250} Temp.	2380	Lime, CaO	1.87
		Magnesia, MgO	0.93
		Potassium Oxide, K_2O	2.46
% Equilibrium Moisture	4.5	Sodium Oxide, Na_2O	0.54
Silica Value	65.51	Sulfur Trioxide, SO_3	0.72
Base: Acid Ratio	0.39	Phos. Pentoxide, P_2O_5	0.28
Free-Swelling Index	5	Strontium Oxide, SrO	0.07
Hardgrove Grind-	48@4.5%	Barium Oxide, BaO	0.03
ability Index	Moisture	Manganese Oxide, Mn_3O_4	0.00
Fouling Index	0.20	Undetermined	0.00
Slagging Index	0.95		-------
			100%

II. REDUCED-SULFUR SOLID FUELS

A reduced-sulfur solid fuel product is described below. Following the description, other characteristics and delivery conditions are listed. After carefully reading these descriptions, you will be asked to indicate how much of this product you would purchase for a particular price differential relative to the REFERENCE PRICE established above.

PRODUCT CHARACTERIZATION

	% Weight	
Proximate Analysis	As Rec'd	Dry Basis
Moisture	6.57	N/A
Ash	/	2.13
Volatile	/	15.12
Fixed Carbon	/	82.75
		100%
Btu/lb.	/	14,721
Sulfur	/	0.45
Alk. as Na_2O	/	0.18

	% Weight
Ultimate Analysis	Dry Basis
Moisture	N/A
Carbon	86.62
Hydrogen	3.90
Nitrogen	2.14
Chlorine	0.10
Sulfur	0.45
Ash	2.13
Oxygen (diff)	4.66
	100%

Ash Fusion	Reducing (°F)
Initial Deform.	2025
Softening (H=W)	2185
Softening (H=1/2W)	2320
Fluid	2365
T_{250} Temp.	2380
% Equilibrium Moisture	4.5
Silica Value	65.51
Base: Acid Ratio	0.39
Free-Swelling Index	5
Hardgrove Grindability Index	48@4.5% Moisture
Fouling Index	0.20
Slagging Index	0.95

Mineral Analysis of Ash	% Weight Ignited Basis
Silica, SiO_2	48.41
Alumina, Al_2O_3	21.14
Titania, TiO_2	1.25
Ferric Oxide, Fe_2O_3	22.10
Lime, CaO	1.87
Magnesia, MgO	0.93
Potassium Oxide, K_2O	2.46
Sodium Oxide, Na_2O	0.54
Sulfur Trioxide, SO_3	0.72
Phos. Pentoxide, P_2O_5	0.28
Strontium Oxide, SrO	0.07
Barium Oxide, BaO	0.03
Manganese Oxide, Mn_3O_4	0.00
Undetermined	0.00
	100%

II. REDUCED-SULFUR SOLID FUELS

A reduced-sulfur solid fuel product is described below. Following the description, other characteristics and delivery conditions are listed. After carefully reading these descriptions, you will be asked to indicate how much of this product you would purchase for a particular price differential relative to the REFERENCE PRICE established above.

PRODUCT CHARACTERIZATION

	% Weight	
Proximate Analysis	As Rec'd	Dry Basis
Moisture	6.57	N/A
Ash	/	9.32
Volatile	/	15.12
Fixed Carbon	/	75.56
		100%
Btu/lb.	/	13,626
Sulfur	/	0.45
Alk. as Na_2O	/	0.18

	% Weight
Ultimate Analysis	Dry Basis
Moisture	N/A
Carbon	80.21
Hydrogen	3.61
Nitrogen	1.91
Chlorine	0.10
Sulfur	0.45
Ash	9.32
Oxygen (diff)	4.40
	100%

Ash Fusion	Reducing (°F)
Initial Deform.	2700+
Softening (H-W)	2700+
Softening (H-1/2W)	2700+
Fluid	2700+
T_{250} Temp.	2900+
% Equilibrium Moisture	4.5
Silica Value	83.25
Base: Acid Ratio	0.17
Free-Swelling Index	5
Hardgrove Grindability Index	48@4.5% Moisture
Fouling Index	0.09
Slagging Index	0.10

Mineral Analysis of Ash	% Weight Ignited Basis
Silica, SiO_2	53.10
Alumina, Al_2O_3	29.95
Titania, TiO_2	1.47
Ferric Oxide, Fe_2O_3	7.31
Lime, CaO	2.24
Magnesia, MgO	1.13
Potassium Oxide, K_2O	2.75
Sodium Oxide, Na_2O	0.79
Sulfur Trioxide, SO_3	0.72
Phos. Pentoxide, P_2O_5	0.12
Strontium Oxide, SrO	0.19
Barium Oxide, BaO	0.12
Manganese Oxide, Mn_3O_4	0.08
Undetermined	0.03
	100%

II. REDUCED-SULFUR SOLID FUELS

A reduced-sulfur solid fuel product is described below. Following the description, other characteristics and delivery conditions are listed. After carefully reading these descriptions, you will be asked to indicate how much of this product you would purchase for a particular price differential relative to the REFERENCE PRICE established above.

PRODUCT CHARACTERIZATION

Proximate Analysis	% Weight As Rec'd	% Weight Dry Basis
Moisture	6.57	N/A
Ash	/	9.32
Volatile	/	15.12
Fixed Carbon	/	75.56
		100%
Btu/lb.	/	13,612
Sulfur	/	0.95
Alk. as Na_2O	/	0.18

Ultimate Analysis	% Weight Dry Basis
Moisture	N/A
Carbon	79.97
Hydrogen	3.60
Nitrogen	1.75
Chlorine	0.10
Sulfur	0.95
Ash	9.32
Oxygen (diff)	4.31
	100%

Ash Fusion	Reducing (°F)
Initial Deform.	2700+
Softening (H=W)	2700+
Softening (H=1/2W)	2700+
Fluid	2700+
T_{250} Temp.	2900+
% Equilibrium Moisture	4.5
Silica Value	83.25
Base: Acid Ratio	0.17
Free-Swelling Index	5
Hardgrove Grindability Index	48@4.5% Moisture
Fouling Index	0.09
Slagging Index	0.10

Mineral Analysis of Ash	% Weight Ignited Basis
Silica, SiO_2	53.10
Alumina, Al_2O_3	29.95
Titania, TiO_2	1.47
Ferric Oxide, Fe_2O_3	7.31
Lime, CaO	2.24
Magnesia, MgO	1.13
Potassium Oxide, K_2O	2.75
Sodium Oxide, Na_2O	0.79
Sulfur Trioxide, SO_3	0.72
Phos. Pentoxide, P_2O_5	0.12
Strontium Oxide, SrO	0.19
Barium Oxide, BaO	0.12
Manganese Oxide, Mn_3O_4	0.08
Undetermined	0.03
	100%

II. REDUCED-SULFUR SOLID FUELS

A reduced-sulfur solid fuel product is described below. Following the description, other characteristics and delivery conditions are listed. After carefully reading these descriptions, you will be asked to indicate how much of this product you would purchase for a particular price differential relative to the REFERENCE PRICE established above.

PRODUCT CHARACTERIZATION

	% Weight			% Weight
Proximate Analysis	As Rec'd	Dry Basis	Ultimate Analysis	Dry Basis
Moisture	6.57	N/A	Moisture	N/A
Ash	/	9.32	Carbon	79.30
Volatile	/	15.12	Hydrogen	3.57
Fixed Carbon	/	75.56	Nitrogen	1.66
		-------	Chlorine	0.10
		100%	Sulfur	1.78
			Ash	9.32
Btu/lb.	/	13,532	Oxygen (diff)	4.27
Sulfur	/	1.78		------
Alk. as Na_2O	/	0.18		100%

Ash Fusion	Reducing (°F)	Mineral Analysis of Ash	% Weight Ignited Basis
Initial Deform.	2700+	Silica, SiO_2	53.10
Softening (H-W)	2700+	Alumina, Al_2O_3	29.95
Softening (H-1/2W)	2700+	Titania, TiO_2	1.47
Fluid	2700+	Ferric Oxide, Fe_2O_3	7.31
T_{250} Temp.	2900+	Lime, CaO	2.24
		Magnesia, MgO	1.13
		Potassium Oxide, K_2O	2.75
% Equilibrium Moisture	4.5	Sodium Oxide, Na_2O	0.79
Silica Value	83.25	Sulfur Trioxide, SO_3	0.72
Base: Acid Ratio	0.17	Phos. Pentoxide, P_2O_5	0.12
Free-Swelling Index	5	Strontium Oxide, SrO	0.19
Hardgrove Grind-ability Index	48@4.5% Moisture	Barium Oxide, BaO	0.12
		Manganese Oxide, Mn_3O_4	0.08
Fouling Index	0.09	Undetermined	0.03
Slagging Index	0.10		-------
			100%

II. REDUCED-SULFUR SOLID FUELS

A reduced-sulfur solid fuel product is described below. Following the description, other characteristics and delivery conditions are listed. After carefully reading these descriptions, you will be asked to indicate how much of this product you would purchase for a particular price differential relative to the REFERENCE PRICE established above.

PRODUCT CHARACTERIZATION

	% Weight	
Proximate Analysis	As Rec'd	Dry Basis
Moisture	6.57	N/A
Ash	/	9.32
Volatile	/	25.14
Fixed Carbon	/	65.54
		100%
Btu/lb.	/	13,782
Sulfur	/	0.45
Alk. as Na_2O	/	0.18

	% Weight
Ultimate Analysis	Dry Basis
Moisture	N/A
Carbon	78.69
Hydrogen	4.32
Nitrogen	1.92
Chlorine	0.10
Sulfur	0.45
Ash	9.32
Oxygen (diff)	5.20
	100%

Ash Fusion	Reducing (°F)
Initial Deform.	2700+
Softening (H=W)	2700+
Softening (H=1/2W)	2700+
Fluid	2700+
T_{250} Temp.	2900+
% Equilibrium Moisture	4.5
Silica Value	83.25
Base: Acid Ratio	0.17
Free-Swelling Index	5
Hardgrove Grindability Index	48@4.5% Moisture
Fouling Index	0.09
Slagging Index	0.10

Mineral Analysis of Ash	% Weight Ignited Basis
Silica, SiO_2	53.10
Alumina, Al_2O_3	29.95
Titania, TiO_2	1.47
Ferric Oxide, Fe_2O_3	7.31
Lime, CaO	2.24
Magnesia, MgO	1.13
Potassium Oxide, K_2O	2.75
Sodium Oxide, Na_2O	0.79
Sulfur Trioxide, SO_3	0.72
Phos. Pentoxide, P_2O_5	0.12
Strontium Oxide, SrO	0.19
Barium Oxide, BaO	0.12
Manganese Oxide, Mn_3O_4	0.08
Undetermined	0.03
	100%

II. REDUCED-SULFUR SOLID FUELS

A reduced-sulfur solid fuel product is described below. Following the description, other characteristics and delivery conditions are listed. After carefully reading these descriptions, you will be asked to indicate how much of this product you would purchase for a particular price differential relative to the REFERENCE PRICE established above.

PRODUCT CHARACTERIZATION

	% Weight			% Weight
Proximate Analysis	As Rec'd	Dry Basis	Ultimate Analysis	Dry Basis
Moisture	6.57	N/A	Moisture	N/A
Ash	/	9.32	Carbon	78.39
Volatile	/	25.14	Hydrogen	4.31
Fixed Carbon	/	65.54	Nitrogen	1.75
		-------	Chlorine	0.10
		100%	Sulfur	0.95
			Ash	9.32
Btu/lb.	/	13,754	Oxygen (diff)	5.18
Sulfur	/	0.95		------
Alk. as Na_2O	/	0.18		100%

Ash Fusion	Reducing (°F)	Mineral Analysis of Ash	% Weight Ignited Basis
Initial Deform.	2700+	Silica, SiO_2	53.10
Softening (H-W)	2700+	Alumina, Al_2O_3	29.95
Softening (H-1/2W)	2700+	Titania, TiO_2	1.47
Fluid	2700+	Ferric Oxide, Fe_2O_3	7.31
T_{250} Temp.	2900+	Lime, CaO	2.24
		Magnesia, MgO	1.13
		Potassium Oxide, K_2O	2.75
% Equilibrium Moisture	4.5	Sodium Oxide, Na_2O	0.79
Silica Value	83.25	Sulfur Trioxide, SO_3	0.72
Base: Acid Ratio	0.17	Phos. Pentoxide, P_2O_5	0.12
Free-Swelling Index	5	Strontium Oxide, SrO	0.19
Hardgrove Grind-ability Index	48@4.5% Moisture	Barium Oxide, BaO	0.12
		Manganese Oxide, Mn_3O_4	0.08
Fouling Index	0.09	Undetermined	0.03
Slagging Index	0.10		-------
			100%

II. REDUCED-SULFUR SOLID FUELS

A reduced-sulfur solid fuel product is described below. Following the description, other characteristics and delivery conditions are listed. After carefully reading these descriptions, you will be asked to indicate how much of this product you would purchase for a particular price differential relative to the REFERENCE PRICE established above.

PRODUCT CHARACTERIZATION

	% Weight	
Proximate Analysis	As Rec'd	Dry Basis
Moisture	6.57	N/A
Ash	/	9.32
Volatile	/	25.14
Fixed Carbon	/	65.54
		100%
Btu/lb.	/	13,670
Sulfur	/	1.78
Alk. as Na_2O	/	0.18

	% Weight
Ultimate Analysis	Dry Basis
Moisture	N/A
Carbon	77.73
Hydrogen	4.27
Nitrogen	1.66
Chlorine	0.10
Sulfur	1.78
Ash	9.32
Oxygen (diff)	5.14
	100%

Ash Fusion	Reducing (°F)
Initial Deform.	2700+
Softening (H-W)	2700+
Softening (H-1/2W)	2700+
Fluid	2700+
T_{250} Temp.	2900+
% Equilibrium Moisture	4.5
Silica Value	83.25
Base: Acid Ratio	0.17
Free-Swelling Index	5
Hardgrove Grindability Index	48@4.5% Moisture
Fouling Index	0.09
Slagging Index	0.10

Mineral Analysis of Ash	% Weight Ignited Basis
Silica, SiO_2	53.10
Alumina, Al_2O_3	29.95
Titania, TiO_2	1.47
Ferric Oxide, Fe_2O_3	7.31
Lime, CaO	2.24
Magnesia, MgO	1.13
Potassium Oxide, K_2O	2.75
Sodium Oxide, Na_2O	0.79
Sulfur Trioxide, SO_3	0.72
Phos. Pentoxide, P_2O_5	0.12
Strontium Oxide, SrO	0.19
Barium Oxide, BaO	0.12
Manganese Oxide, Mn_3O_4	0.08
Undetermined	0.03
	100%

II. REDUCED-SULFUR SOLID FUELS

A reduced-sulfur solid fuel product is described below. Following the description, other characteristics and delivery conditions are listed. After carefully reading these descriptions, you will be asked to indicate how much of this product you would purchase for a particular price differential relative to the REFERENCE PRICE established above.

PRODUCT CHARACTERIZATION

	% Weight	
Proximate Analysis	As Rec'd	Dry Basis
Moisture	6.57	N/A
Ash	/	9.32
Volatile	/	35.26
Fixed Carbon	/	55.42
		100%
Btu/lb.	/	13,859
Sulfur	/	0.45
Alk. as Na_2O	/	0.18

	% Weight
Ultimate Analysis	Dry Basis
Moisture	N/A
Carbon	77.10
Hydrogen	4.94
Nitrogen	1.91
Chlorine	0.10
Sulfur	0.45
Ash	9.32
Oxygen (diff)	6.18
	100%

Ash Fusion	Reducing (°F)
Initial Deform.	2700+
Softening (H=W)	2700+
Softening (H=1/2W)	2700+
Fluid	2700+
T_{250} Temp.	2900+
% Equilibrium Moisture	4.5
Silica Value	83.25
Base: Acid Ratio	0.17
Free-Swelling Index	5
Hardgrove Grindability Index	48@4.5% Moisture
Fouling Index	0.09
Slagging Index	0.10

Mineral Analysis of Ash	% Weight Ignited Basis
Silica, SiO_2	53.10
Alumina, Al_2O_3	29.95
Titania, TiO_2	1.47
Ferric Oxide, Fe_2O_3	7.31
Lime, CaO	2.24
Magnesia, MgO	1.13
Potassium Oxide, K_2O	2.75
Sodium Oxide, Na_2O	0.79
Sulfur Trioxide, SO_3	0.72
Phos. Pentoxide, P_2O_5	0.12
Strontium Oxide, SrO	0.19
Barium Oxide, BaO	0.12
Manganese Oxide, Mn_3O_4	0.08
Undetermined	0.03
	100%

II. REDUCED-SULFUR SOLID FUELS

A reduced-sulfur solid fuel product is described below. Following the description, other characteristics and delivery conditions are listed. After carefully reading these descriptions, you will be asked to indicate how much of this product you would purchase for a particular price differential relative to the REFERENCE PRICE established above.

PRODUCT CHARACTERIZATION

	% Weight			% Weight
Proximate Analysis	As Rec'd	Dry Basis	Ultimate Analysis	Dry Basis
Moisture	6.57	N/A	Moisture	N/A
Ash	/	9.32	Carbon	76.81
Volatile	/	35.26	Hydrogen	4.92
Fixed Carbon	/	55.42	Nitrogen	1.75
		-------	Chlorine	0.10
		100%	Sulfur	0.95
			Ash	9.32
Btu/lb.	/	13,827	Oxygen (diff)	6.15
Sulfur	/	0.95		------
Alk. as Na_2O	/	0.18		100%

Ash Fusion	Reducing (°F)	Mineral Analysis of Ash	% Weight Ignited Basis
Initial Deform.	2700+	Silica, SiO_2	53.10
Softening (H-W)	2700+	Alumina, Al_2O_3	29.95
Softening (H-1/2W)	2700+	Titania, TiO_2	1.47
Fluid	2700+	Ferric Oxide, Fe_2O_3	7.31
T_{250} Temp.	2900+	Lime, CaO	2.24
		Magnesia, MgO	1.13
		Potassium Oxide, K_2O	2.75
% Equilibrium Moisture	4.5	Sodium Oxide, Na_2O	0.79
Silica Value	83.25	Sulfur Trioxide, SO_3	0.72
Base: Acid Ratio	0.17	Phos. Pentoxide, P_2O_5	0.12
Free-Swelling Index	5	Strontium Oxide, SrO	0.19
Hardgrove Grindability Index	48@4.5% Moisture	Barium Oxide, BaO	0.12
		Manganese Oxide, Mn_3O_4	0.08
Fouling Index	0.09	Undetermined	0.03
Slagging Index	0.10		-------
			100%

II. REDUCED-SULFUR SOLID FUELS

A reduced-sulfur solid fuel product is described below. Following the description, other characteristics and delivery conditions are listed. After carefully reading these descriptions, you will be asked to indicate how much of this product you would purchase for a particular price differential relative to the REFERENCE PRICE established above.

PRODUCT CHARACTERIZATION

	% Weight			% Weight
Proximate Analysis	As Rec'd	Dry Basis	Ultimate Analysis	Dry Basis
Moisture	6.57	N/A	Moisture	N/A
Ash	/	9.32	Carbon	76.16
Volatile	/	35.26	Hydrogen	4.88
Fixed Carbon	/	55.42	Nitrogen	1.66
		-------	Chlorine	0.10
		100%	Sulfur	1.78
			Ash	9.32
Btu/lb.	/	13,744	Oxygen (diff)	6.10
Sulfur	/	1.78		------
Alk. as Na_2O	/	0.18		100%

Ash Fusion	Reducing (°F)
Initial Deform.	2700+
Softening (H-W)	2700+
Softening (H-1/2W)	2700+
Fluid	2700+
T_{250} Temp.	2900+
% Equilibrium Moisture	4.5
Silica Value	83.25
Base: Acid Ratio	0.17
Free-Swelling Index	5
Hardgrove Grindability Index	48@4.5% Moisture
Fouling Index	0.09
Slagging Index	0.10

Mineral Analysis of Ash	% Weight Ignited Basis
Silica, SiO_2	53.10
Alumina, Al_2O_3	29.95
Titania, TiO_2	1.47
Ferric Oxide, Fe_2O_3	7.31
Lime, CaO	2.24
Magnesia, MgO	1.13
Potassium Oxide, K_2O	2.75
Sodium Oxide, Na_2O	0.79
Sulfur Trioxide, SO_3	0.72
Phos. Pentoxide, P_2O_5	0.12
Strontium Oxide, SrO	0.19
Barium Oxide, BaO	0.12
Manganese Oxide, Mn_3O_4	0.08
Undetermined	0.03

	100%

APPENDIX D. THE POPULATION AND SAMPLE:

The population of coal-fired power plants from which we drew our sample consisted of all unscrubbed plants in states where Illinois coal was sold in 1985. These plants are listed in Table D-I with an asterisk indicating the plants in the sample and a double asterisk indicating those sample plants from which we received no response. Plants with a plus were in the pre-test sample but were excluded from the analysis.

TABLE D-I: Power Plant Population and Sample

PLANT	CAPACITY	UTILITY	STATE
*BARRY	1771	ALABAMA POWER CO (SC)	AL
GADSDEN	138	ALABAMA POWER CO (SC)	AL
*GORGAS 2 AND 3	1486	ALABAMA POWER CO (SC)	AL
GREENE	568	ALABAMA POWER CO (SC)	AL
*GASTON	2013	ALABAMA POWER CO (SC)	AL
JAMES MILLER	706	ALABAMA POWER CO (SC)	AL
*AMES	118	AMES, CITY OF	IA
*MADRID	1200	ASSOCIATED ELEC COOP-MISSOURI	MO
COLEMAN	521	BIG RIVERS RURAL ELECTRIC COOP	KY
*REID-HENDERSONII	820	BIG RIVERS RURAL ELECTRIC COOP	KY
*CHAMOIS	59	CENTRAL ELEC POWER COOP-MISSOURI	MO
+EDWARDS	780	CENTRAL ILLINOIS LIGHT	IL
+WALLACE	305	CENTRAL ILLINOIS LIGHT	IL
*COFFEEN	1005	CENTRAL ILLINOIS PUBLIC SERVICE	IL
GRAND TOWER	195	CENTRAL ILLINOIS PUBLIC SERVICE	IL
HUTSONVILLE	200	CENTRAL ILLINOIS PUBLIC SERVICE	IL
*MEREDOSIA	564	CENTRAL ILLINOIS PUBLIC SERVICE	IL
CRAWFORD	598	COMMONWEALTH EDISON	IL
JOLIET	360	COMMONWEALTH EDISON	IL
*KINCAID	1319	COMMONWEALTH EDISON	IL
*POWERTON	1786	COMMONWEALTH EDISON	IL
WAUKEGAN	803	COMMONWEALTH EDISON	IL
*WILL COUNTY	1269	COMMONWEALTH EDISON	IL
FISK	374	COMMONWEALTH EDISON	IL
COBB-SANDUSKY SG	511	CONSUMERS POWER	MI
*KARN-WEADOCK	1761	CONSUMERS POWER	MI
*CAMPBELL	1420	CONSUMERS POWER	MI
WEADOCK-SANDUSKY	615	CONSUMERS POWER	MI
WHITING	325	CONSUMERS POWER	MI
*ALMA-MADGETT	575	DAIRYLAND POWER COOPERATIVE	WI
GENOA NO.3	360	DAIRYLAND POWER COOPERATIVE	WI
CONNERS CREEK	540	DETROIT EDISON CO	MI
HARBOR BEACH	121	DETROIT EDISON CO	MI
MARYSVILLE	200	DETROIT EDISON CO	MI
+MONROE	3280	DETROIT EDISON CO	MI
RIVER ROUGE	933	DETROIT EDISON CO	MI
+ST CLAIR	1905	DETROIT EDISON CO	MI
TRENTON CHANNEL	776	DETROIT EDISON CO	MI
BELLE RIVER		DETROIT EDISON CO	MI
*COOPER	321	EAST KENTUCKY RURAL ELEC COOP	KY
DALE	176	EAST KENTUCKY RURAL ELEC COOP	KY
*FAIR	63	CENTRAL IOWA POWER COOP	IA
*JOPPA	1100	ELECTRIC ENERGY	IL
RIVERTON	135	EMPIRE DIST ELECTRIC	KS
*ASBURY	213	EMPIRE DIST ELECTRIC	MO
*CRYSTAL RIVER	1629	FLORIDA POWER CORP	FL
*DEERHAVEN	326	GAINESVILLE-ALACHUA COUNTY UTILS	FL
ARKWRIGHT	181	GEORGIA POWER (SOUTHERN CO)	GA

ATKINSON-MCDONOUGH	240	GEORGIA POWER (SOUTHERN CO)	GA
*BOWEN	3499	GEORGIA POWER (SOUTHERN CO)	GA
HAMMOND	953	GEORGIA POWER (SOUTHERN CO)	GA
*HARLLEE BRANCH	1746	GEORGIA POWER (SOUTHERN CO)	GA
MCDONOUGH		GEORGIA POWER (SOUTHERN CO)	GA
MITCHELL	218	GEORGIA POWER (SOUTHERN CO)	GA
*YATES	1488	GEORGIA POWER (SOUTHERN CO)	GA
*WANSLEY	1904	GEORGIA POWER (SOUTHERN CO)	GA
SCHERER	891	GEORGIA POWER (SOUTHERN CO)	GA
*J B SIMMS	108	GRAND HAVEN LIGHT & POWER	MI
*CRIST	1229	GULF POWER	FL
SMITH	340	GULF POWER	FL
**HENDERSON	41	HENDERSON MUNICIPAL PWR AND LT	KY
*FRANK E RATTS	233	HOOSIER ENERGY DIV-INDIANA REC	IN
*BALDWIN	1892	ILLINOIS POWER	IL
*HAVANA	718	ILLINOIS POWER	IL
HENNEPIN	306	ILLINOIS POWER	IL
VERMILION	182	ILLINOIS POWER	IL
WOOD RIVER	650	ILLINOIS POWER	IL
**BLUE VALLEY	115	CITY OF INDEPENDENCE PWR AND LT	MO
*STOUT	843	INDIANAPOLIS POWER AND LIGHT	IN
PRITCHARD	394	INDIANAPOLIS POWER AND LIGHT	IN
DUBUQUE	81	INTERSTATE POWER	IA
+LANSING	339	INTERSTATE POWER	IA
+KAPP	237	INTERSTATE POWER	IA
FOX LAKE	105	INTERSTATE POWER	MN
6TH ST	92	IOWA ELECTRIC LIGHT AND POWER	IA
*PRAIRE CREEK 1-4	245	IOWA ELECTRIC LIGHT AND POWER	IA
SUTHERLAND	157	IOWA ELECTRIC LIGHT AND POWER	IA
RIVERSIDE	202	IOWA-ILLINOIS GAS AND ELECTRIC	IA
*LOUISA	650	IOWA-ILLINOIS GAS AND ELECTRIC	IA
*COUNCIL BLUFFS	856	IOWA POWER AND LIGHT	IA
DES MOINES	270	IOWA POWER AND LIGHT	IA
**GEORGE NEAL 1/4	1686	IOWA PUBLIC SERVICE	IA
BURLINGTON	188	IOWA SOUTHERN UTILITIES	IA
*OTTUMWA	725	IOWA SOUTHERN UTILITIES	IA
KAW	161	KANSAS CITY BD PUBLIC UTILITIES	KS
**QUINDARO	333	KANSAS CITY BD PUBLIC UTILITIES	KS
NEARMAN	262	KANSAS CITY BD PUBLIC UTILITIES	KS
*HAWTHORNE	908	KANSAS CITY POWER AND LIGHT	MO
MONTROSE	563	KANSAS CITY POWER AND LIGHT	MO
IATAN	726	KANSAS CITY POWER AND LIGHT	MO
*TECUMSEH	306	KANSAS POWER AND LIGHT CO	KS
**BROWN	740	KENTUCKY UTILITIES	KY
GHENT	1670	KENTUCKY UTILITIES	KY
*PLANT 3-MCINTOSH	563	LAKELAND DEPT OF ELEC WTR UTILS	FL
*ECKERT	386	LANSING BOARD OF WATER AND LIGHT	MI
ERICKSON	160	LANSING BOARD OF WATER AND LIGHT	MI
*BLOUNT	196	MADISON GAS AND ELECTRIC	WI
*SIBLEY	524	MISSOURI PUBLIC SERVICE	MO
BAILLY	616	NORTHERN INDIANA PUBLIC SERVICE	IN
MITCHELL	529	NORTHERN INDIANA PUBLIC SERVICE	IN

*MICHIGAN CITY	732	NORTHERN INDIANA PUBLIC SERVICE	IN
*ROLLIN SCHAHFER	1032	NORTHERN INDIANA PUBLIC SERVICE	IN
*BLACK DOG	481	NORTHERN STATES POWER	MN
HIGH BRIDGE	392	NORTHERN STATES POWER	MN
*KING	598	NORTHERN STATES POWER	MN
RIVERSIDE	378	NORTHERN STATES POWER	MN
**HOOT LAKE	137	OTTER TAIL POWER	MN
*SMITH	416	OWENSBORO MUNICIPAL UTILITIES	KY
CAYUGA	1062	PUBLIC SERVICE CO OF INDIANA	IN
EDWARDSPORT	144	PUBLIC SERVICE CO OF INDIANA	IN
NOBLESVILLE	100	PUBLIC SERVICE CO OF INDIANA	IN
GALLAGHER	600	PUBLIC SERVICE CO OF INDIANA	IN
+WABASH RIVER	962	PUBLIC SERVICE CO OF INDIANA	IN
**WHITEWATER	93	RICHMOND POWER AND LIGHT	IN
*SILVER LAKE	98	ROCHESTER DEPT PUBLIC UTILITIES	MN
*PORT WENTWORTH	356	SAVANNAH ELECTRIC AND POWER	GA
MCINTOSH	178	SAVANNAH ELECTRIC AND POWER	GA
*MARION	272	SOUTHERN ILLINOIS POWER COOP	IL
*CULLEY	415	SOUTHERN INDIANA GAS AND ELEC	IN
WARRICK	323	SOUTHERN INDIANA GAS AND ELEC	IN
*LAKESIDE	135	SPRINGFIELD WTR LT AND PWR DEPT	IL
*JAMES RIVER	253	CITY UTILITIES OF SPRINGFIELD	MO
*GANNON	1270	TAMPA ELECTRIC	FL
COLBERT	1350	TENNESSEE VALLEY AUTHORITY	AL
*SHAWNEE	1750	TENNESSEE VALLEY AUTHORITY	KY
ALLEN	990	TENNESSEE VALLEY AUTHORITY	TN
BULL RUN	950	TENNESSEE VALLEY AUTHORITY	TN
*CUMBERLAND	2600	TENNESSEE VALLEY AUTHORITY	TN
GALLATIN	1255	TENNESSEE VALLEY AUTHORITY	TN
SEVIER	800	TENNESSEE VALLEY AUTHORITY	TN
*JOHNSONVILLE	1485	TENNESSEE VALLEY AUTHORITY	TN
*KINGSTON	1700	TENNESSEE VALLEY AUTHORITY	TN
WATTS BAR	240	TENNESSEE VALLEY AUTHORITY	TN
*LABADIE	2482	UNION ELECTRIC	MO
MERAMEC	923	UNION ELECTRIC	MO
SIOUX	1100	UNION ELECTRIC	MO
*RUSH ISLAND	1241	UNION ELECTRIC	MO
*PRESQUE ISLE	628	UPPER PENINSULA GEN CO	MI
*OAK CREEK	500	WISCONSIN ELECTRIC POWER	WI
PORT WASHINGTON	400	WISCONSIN ELECTRIC POWER	WI
S OAK CREEK		WISCONSIN ELECTRIC POWER	WI
VALLEY	270	WISCONSIN ELECTRIC POWER	WI
*PLEASANT PRAIRIE	617	WISCONSIN ELECTRIC POWER	WI
**EDGEWATER	477	WISCONSIN POWER AND LIGHT	WI
NELSON DEWEY	227	WISCONSIN POWER AND LIGHT	WI
ROCK RIVER	150	WISCONSIN POWER AND LIGHT	WI
**COLUMBIA	1112	WISCONSIN POWER AND LIGHT	WI
PULLIAM	373	WISCONSIN PUBLIC SERVICE CORP	WI
*WESTON	457	WISCONSIN PUBLIC SERVICE CORP	WI
*STATE LINE	614	COMMONWEALTH EDISON-INDIANA	IN
**CLIFTY CREEK	1304	INDIANA-KENTUCKY ELECTRIC CORP	IN
**BIG SANDY	1097	KENTUCKY POWER (AEP)	KY

BREED	496	INDIANA AND MICHIGAN ELEC (AEP)	IN
TANNERS CREEK	1100	INDIANA AND MICHIGAN ELEC (AEP)	IN
**ROCKPORT	1300	INDIANA AND MICHIGAN ELEC (AEP)	IN

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